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Brexit and Digital Technology Adoption of UK SMEs

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ABSTRACT

This paper examines the impact of the Brexit referendum on digital technology adoption by small and medium-sized enterprises in the UK from 2013-2019. Combining existing survey measures from the Longitudinal Small Business Survey with novel data on digital technology adoption from firms' own websites, we provide detailed and timely measurements to gain deeper insights into SMEs' reactions to a major policy shock. Leveraging the Brexit referendum as a trade policy uncertainty shock, we employ a difference-in-differences approach to investigate the response of SMEs. We find that SMEs adjust to this shock by scaling back their adoption of e-commerce-related technologies, along with other digital technologies. These effects cut across multiple sectors, extending beyond those traditionally associated with the trade of goods to also include service sectors. Overall, these findings provide novel insights into the strategies SMEs adopt in response to significant policy-led disruptions, highlighting their decision to significantly reduce the use of digital technologies. This charge could potentially influence their long-term productivity levels, suggesting an important area for further investigation and policy focus.

JEL classification: F13, L25, O47

Brexit, SMEs, digital technology adoption

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1. INTRODUCTION

On June 23rd, 2016, the United Kingdom (UK) voted to leave the European Union (EU), a decision that drastically shifted expectations for the UK's future relationship with the EU. The resulting significant trade barriers have led to a decrease in trade for UK firms in both imports (Freeman et al., 2022) and exports (Crowley et al., 2018). The Brexit referendum has led to a decline in investment and productivity for larger firms (Bloom et al., 2019), but little is known about the effect of this shock through impacts on innovation among Small and Medium Enterprises (SMEs) in the UK. SMEs are the backbone of the economy, making up 99.9% of all private firms in the UK (ONS, 2017) and providing 60% of all jobs (Department for Business Energy and Industrial Strategy, 2021). This is even more the case for local economies in South West England and Wales, where their employment makes up 70% of employment in the private sector (Department for Business Energy and Industrial Strategy, 2021). We exploit the Brexit referendum as a trade policy uncertainty shock, studying how SMEs that trade with the EU adjust their digital technology adoption and compare it to firms that do not have direct ties with the EU. In addition, we use the inter-regional variation in the Brexit referendum, exploiting the magnitude of the shock that may have been unexpected, measured by the differences between survey-based expectations and the actual Brexit vote, to estimate the local effect on firm-level performance. We employ novel data sources on digital technology adoption to provide detailed measures to explore differences in how SMEs respond to this trade policy uncertainty shock.

A large body of literature has reported a strong link between digital technology adoption and productivity gains at the country and firm level (Draca et al., 2009; Van Reenen et al., 2010; Bloom et al., 2012). In light of the UK's productivity growth already lagging behind comparable nations since the global economic and financial crises (Financial Times, 2018), the economic downturn and productivity slowdown catalysed by Brexit (Sampson, 2017; Bloom et al., 2019) underscores the necessity to understand the response of the largest group of private firms to such a major shock. SMEs are often viewed as drivers of productivity, especially those that are innovative and growth-oriented (Schneider and Veugelers, 2010). Crucially, it's this particular group that has voiced considerable concern about the effects of Brexit (Brown et al., 2019). Despite this, evidence is missing on how they are affected when it comes to digital technology adoption, a key component of productivity growth (Gal et al., 2019). We seek to fill this knowledge gap, providing insights into which firms and digital technologies have been most impacted by Brexit. Such findings should prove useful for policymakers, empowering them with the information needed to

design and implement effective measures that mitigate some of the detrimental effects on firms. This is of paramount importance, particularly in the long run, as alleviating some of the negative effects of Brexit on UK firms is intrinsically tied to overcoming the ongoing productivity decline affecting UK living standards and SMEs' growth potential.

We study the effect of the Brexit referendum on the digital technology adoption of UK SMEs from 2013-2019. We combine survey data from the Longitudinal Small Business Survey (LSBS) with novel data on digital technology adoption from firms' websites to provide detailed and timely measurements to gain deeper insights into SMEs' reactions to this shock. We use a difference-in-differences approach, with the Brexit referendum as a trade policy uncertainty shock that imposes higher potential trade costs and heightens uncertainty among exposed firms that depend on the EU for much of their trading activities. We study how firms that trade with the EU respond and find that they adapt by reducing digital technologies. We find a negative effect for digital technologies that are used for e-commerce, including payment technologies, which are significantly decreased, suggesting that firms cut back in the form of trade-enhancing digital technologies. These effects are driven by multiple sectors, extending beyond those traditionally associated with the trade of goods to also include service sectors. In addition, we find that firms most exposed to the shock reduce digital technologies not directly linked to e-commerce, suggesting a wider and more substantial impact of Brexit on SMEs' technology adoption.

This study contributes to three different types of literature. First, it links to the growing literature on how Brexit affects firm-level outcomes. The Brexit referendum changed expectations about future UK-EU relations and business expectations, leading firms to reduce trade with the EU (Crowley et al., 2018) as well as decreasing investment and innovation (Brown et al., 2019). It contributes to this strand by complementing existing literature on the response through innovation, by looking at SMEs and their digital behaviour, showing that SMEs exposed to this shock experienced, on average, a reduction in their digital technologies compared to before the Brexit referendum.

Second, it relates to the literature on trade policy reforms and uncertainty. While a large number of studies have demonstrated that trade liberalisation is linked to higher growth (Pavcnik, 2002; Melitz, 2003; Amiti and Konings, 2007; Bloom et al., 2016; Handley and Limão, 2017), Brexit can be seen through the lens of reverse trade reform. These growth-increasing effects of trade liberalisation reforms materialise through improved productivity and allocation and higher innovation. It has been shown that trade policy uncertainty negatively affects firms' export investments, particularly when high sunk costs in trade are

involved (Handley and Limão, 2015). Thus, with high trade policy uncertainty, negative effects on growth through lower trade, investment and innovation would be expected.

Third, our study explores the evolution of digital technology adoption metrics, facilitated by the linking of existing survey data with novel online data sources. It develops novel measures for technology adoption by leveraging ever-increasing volumes of data available from businesses' websites. Matching these novel measures to existing data sources allows us to create more detailed and timely estimates on technology adoption and SMEs' digital behaviour. These can be used to have a more accurate picture of adjustments made by firms in their technology portfolios over time.

This paper is organised as follows: we first summarise relevant literature, focusing on the effect of Brexit on UK firms, particularly SMEs. We then describe the data for this study, consisting of LSBS data and digital technologies based on firms' website data. We show some descriptive statistics linked to Brexit and trends in digital technologies and explain in the methodology section how we identify the effect of Brexit on SMEs' technology adoption of SMEs. We then estimate the results for different technology groups and discuss the findings in the last section.

2. RELATED LITERATURE

In this section, we first summarise relevant literature, pointing out the state of the art regarding the effect of Brexit on UK firms, focusing on SMEs. We then show how there is a gap regarding the impact of Brexit on SMEs' digital technology adoption and discuss how this study can provide novel insights. We contribute to the growing literature by creating detailed measures of digital technologies at the firm level and then estimating the effect of Brexit. There is substantial research on the impact of Brexit on the UK economy (see, e.g. Dhingra et al., 2022; Du et al., 2022; Hantzsche et al., 2019; Van Reenen, 2016), with the overall conclusion that Brexit will make the UK economy poorer than it would have been otherwise due to barriers to trade and migration (Sampson, 2017). The decision to leave the EU has had a large negative impact on the UK economy from 2016 to 2019, including a decline in investment, higher import and consumer prices, as well as a decreased growth in GDP and real wages (Dhingra and Sampson, 2022).

Looking at regional and firm-level outcomes, previous research has also studied the impact of Brexit on regional productivity, governance response and competitiveness (Fingleton et al., 2022; Thissen et al., 2020; Billing et al., 2019), the trade exposure of UK regions (Chen et al., 2018), consumer prices (Bakker et al., 2022), firm size and age (Uddin et al., 2022),

firm investment (Górnicka, 2018; Bloom et al., 2019), turnover, sales and trade in the textile and apparel industry (Casadei and Iammarino, 2021), the potential impact on SMEs (Brown et al., 2019) and on the strategic intentions of SMEs (Brown et al., 2020).

2.1 Brexit as trade policy uncertainty shock

With the decision to leave the single market in 2016, the Brexit referendum created increased trade friction between the UK and the EU market. With the expectations of rising trade barriers linked to the largest trade partner of the UK, firms become more pessimistic regarding their outlook on the future and the business environment. Firms are likely to anticipate higher costs from importing, lower profits and increased administrative work and thus respond with reduced trade with the EU. This has already been observed, with the potential future trade barriers leading to a fall in trade with the EU (Brown et al., 2018; Crowley et al., 2018) and a decrease in investment (Gornicka, 2018, Bloom et al., 2019). Trade is generally linked with productivity increases, with the literature showing that the liberalisation of trade is linked to growth in income, innovation, and employment (Frankel and Romer, 1999; Pavcnik, 2002; Amiti and Konings, 2007; Bloom et al., 2016; Handley and Limão, 2017). This effect could be due to productivity changes stemming from an improved allocation between firms (Pavcnik, 2002) or within-firm adjustments linked to trade. Thus, from an aggregated perspective, we would expect a reverse trade liberalisation shock to decrease productivity and innovation.

In addition to being a trade policy shock, the Brexit referendum created uncertainty for firms that trade with the EU. The Brexit referendum was not only a trade policy shock but a trade policy uncertainty shock. There is substantial literature on the effects of uncertainty, the business cycle, output and investment (see, e.g., Bernanke, 1983, Bloom, 2009; Basu and Bundick, 2017; Fernández-Villaverde and Guerrón-Quintana, 2020), showing that an increase in uncertainty about the future leads to a decrease in output, investment and consumption. The effects of an uncertainty shock tend to be larger when tightly linked to political uncertainty (Redl, 2017), as is the case for Brexit.

Directly after the referendum, uncertainty was induced and high, as shown in Figure 9 in the appendix. It increased until September 2018 when the EU rejected the UK's proposal at the Salzburg summit, which raised the likelihood of a Brexit without an agreement and increased potential future trade costs. In November 2018, a withdrawal agreement between the UK and the EU was reached but was later refused by the UK parliament. With uncertainty still at a high level, it kept increasing until March 2019, when it was originally

planned for the UK to leave the European Union. Uncertainty began to decrease once Brexit was delayed until October 31, 2019, while it was still high in July 2019 and greater than it had been in the initial two years following the referendum (Bloom et al., 2019).

The Brexit referendum was a trade uncertainty shock that persisted for more than three years. Given the lack of clarity regarding how and when the UK would leave the EU, what conditions would follow afterwards and the extent to which the UK economy would be impacted by it, it was more up to the firm's expectations how to adapt to this novel situation than actual knowledge about how it would develop. Related research has shown that firms are likely to act more cautiously, reducing their investment and innovation (Górnicka, 2018; Brown et al., 2019). This might happen instantly or with a slower response. Hassan et al. (2020) finds an immediate effect of Brexit with the largest marginal effect on international firm investment in 2017. In contrast, Bloom et al. (2019) find a gradual effect for UK firms. One explanation might be a "cautionary effect" induced by uncertainty (Guiso and Parigi, 1999) describing how firms slowly adapt their behaviour, implying that we would be able to observe an effect a few years after the referendum.

2.2 The effect of Brexit on UK firms

Multiple papers have looked at the effect of Brexit on UK firms. This includes the effect on investment and productivity (Bloom et al., 2018; Górnicka, 2018), on the stock market (Shahzad et al., 2019), on UK exports (Crowley et al., 2018), the potential impact on SMEs (Brown et al., 2018; Brown et al., 2020), but also global firms (Hassan et al., 2021). Bloom et al. (2018) estimate the effect of the anticipation of Brexit three years after the referendum, finding a substantial effect on firm investment and UK productivity, with Brexit decreasing investment by approximately 11% and UK productivity by around 2% to 5%. Their findings are representative of larger UK firms, as they use the Bureau van Dijk FAME database, with their sampling being based on UK businesses that have more than ten employees. They also find that firms more heavily exposed to the EU are more affected by Brexit, which is similar to the findings of other studies, such as Davies and Studnicka (2018) pointing out that a firm's global value chain position plays a major role, with those with higher EU exposure being more impacted. Evaluating the effect of Brexit on exporting behaviour of UK firms, Crowley et al. (2018) find that a substantial amount of firms have exported less and/or exited from exporting to the EU.

The amount of studies focusing on the effect of Brexit on SMEs is limited, in particular, lacking evidence on the actual impact of Brexit. Brown et al. (2019) focus on the potential impact of Brexit by looking at the expectations of SMEs after the Brexit referendum (2016-

2017), stemming from extra questions in the LSBS about whether and why Brexit is perceived as a major obstacle. They find heterogeneity in their results, with more knowledge-intensive, larger and internationally oriented businesses more concerned about the potential impact of Brexit (Brown et al., 2019). Another study focusing on SMEs uses a mixed-methods approach for the case of Scotland, combining survey data and interviews to show that a large part of SMEs was struggling operationally and strategically to deal with the uncertainty created by Brexit (Brown et al., 2020).

2.3 The Geography of Discontent

A large number of studies has looked at the determinants of Brexit, emphasising the critical role of economic factors and geography. Other drivers have also been pointed out, in particular demographic and cultural factors. The economic hypothesis has found popularity given that economically left behind regions are those with a majority voting to leave (Norris and Inglehart, 2018). These regions include Yorkshire, Eastern England, and the Midlands, where more voters tend to be older, white and less educated. Particularly those regions that have been historically reliant on mills and mining industries, with poorer households, higher unemployment and lower educational attainment, have been showing their discontent with the status quo. Lacking opportunities and poor future prospects have led these “places that don’t matter” to revolt using the ballot box (Rodríguez-Pose, 2018). Indeed, the Brexit vote varies substantially across space, as shown in Figure 8 in the appendix.

Looking at the district level shows that the education levels of the population, low wages, high unemployment and past reliance on manufacturing jobs are major predictors of voting in favour of Brexit (Becker et al., 2017). The gap between those benefiting and losing from economic globalisation has been found to be crucial for the vote (Hobolt, 2016), but also a growing gap between the internationalisation of local firms and their employees’ “localistic” viewpoints (Crescenzi et al., 2018). Others point out the role of austerity, arguing that it has fuelled support for UKIP, transformed the political landscape and is the reason why the votes towards “Leave” outweigh the “Remain” ones (Fetzer, 2019). Zooming in on geography, a close link between geographic voting behaviour and spatial productivity has been pointed out in the case of Brexit by scholars. Differences in characteristics across spaces being reflected in the populist voting pattern is referred to as the “geography of discontent“ (Dijkstra et al., 2020; McCann and Ortega-Argilés, 2021). For this reason, we are also interested in assessing how the spatial differences in the Brexit vote have affected SMEs’ digital technology adoption of SMEs.

2.4 Gap in the Literature and Contribution

Despite this evidence, less is known about how different SMEs respond to this trade policy uncertainty shock in terms of digital technologies. There is a substantial gap in the literature on quantifying the actual impact of the Brexit referendum since its withdrawal in 2020 on SMEs and their ability to innovate. To the best of our knowledge, no study has yet assessed SMEs' digital performance. Given the relevance of new technologies in reducing costs and enabling productivity gains, having a better understanding of the differential impact of this productivity shock on SMEs and their adoption of innovative technologies is vital, as SMEs play a central role in shaping regional economic outcomes. This study contributes to the existing literature by employing web scraping tools to identify technologies used in SMEs' website source code. This information can be used to track shifts in technology adoption that result from the Brexit vote, with a focus on different technologies and industries affected.

3. SMES' POTENTIAL DIGITAL RESPONSE TO THE BREXIT REFERENDUM

This section discusses SMEs' potential response in terms of digital technologies and how we would expect them to adjust their behaviour after the Brexit referendum. The Brexit referendum is conceptualised as a trade policy uncertainty shock that led to higher potential future trade costs and, thus, more negative expectations about the business environment for firms trading with the EU. Given higher future costs linked with uncertainty, we would expect SMEs to respond in multiple ways. First, they would likely reduce trade and innovation, which has already been shown by Brown et al. (2019). We would also expect this response to be reflected in digital technologies by observing a reduction of technologies linked to e-commerce, such as payment or shipping technology. This could be related to digital technologies that are free of charge or premium. Despite SMEs trading less than larger firms, previous research has shown that because of constrained resources and lacking resilience, SMEs tend to be disproportionately affected when it comes to higher uncertainty stemming from an unanticipated shock, in particular, linked to investment irreversibility (Ghosal & Ye, 2015). Thus, we expect a reduction in e-commerce-related digital technologies for firms exposed by trading with the EU.

Second, firms have reduced capital investment, including investment in R&D and likely also related to digital technologies due to higher uncertainty about the future. Existing evidence shows that Brexit has led UK firms to cut investment (Górnicka, 2018; Bloom et al., 2019), including SMEs reducing investment in innovation (Brown et al., 2019). Therefore, we would also expect SMEs to cut costs on digital technologies, decreasing, in particular, the amount spent on cost-intensive technologies and digital technologies less relevant to the core business.

Third, in addition to SMEs reducing digital technologies related to e-commerce and cutting investment, we are discussing a third channel, which is through a change in SMEs' strategic intentions.nIn this case, the direction of their strategic planning changes, given the unexpected trade uncertainty shock. Instead of planning growth-related activities, the management of the SMEs will spend more time conducting an assessment of how Brexit will affect the firm and devising strategies on how to respond to this shock. The time on expansion is replaced by Brexit planning. Bloom et al. (2019) show that this is the case for UK firms, being one of the main channels why firms become less productive after the Brexit referendum. We expect firms to spend less time searching and learning how to adopt a free or premium technology for this channel. Thus, we could also expect to see a decrease in free digital technologies on firms' websites. For all three channels, we would expect a large number of those SMEs that trade with the EU to be affected, given that the EU is their major trade partner of UK firms.

4. DATA

4.1 Longitudinal Small Business Survey

The Longitudinal Small Business Survey is compiled by the UK Department for Business, Energy, and Industrial Strategy and is available yearly from 2015-2021 as a cross-sectional and longitudinal survey. It is a large-scale telephone survey that covers around 0.1% of the UK SME population, with approximately between 6,500 and 16,000 SMEs participating every year (UK Data Service, 2019). Every year, the LSBS surveys business with less than 250 employees, with the majority of questions being repeated every year. The sample is stratified by UK region, sector, and size, covering information on performance measures of SMEs, including employment, innovation, exporting and turnover (UK Data Service, 2019).

We choose the LSBS to study the effect on SMEs for multiple reasons. First, it covers a large population of firms. Second, it includes rich information on firm-level characteristics.

Information on sector, region, turnover, trade, and innovation allows us to classify firms according to relevant groups. Third, it includes specific questions on Brexit, making it possible to understand firms' perceptions towards Brexit. The survey is conducted in the second half of each year, with the perception of Brexit being asked after the referendum in 2016. The surveys in 2017 and 2018 were carried out during a time of high uncertainty created by Brexit, and in 2019 the fieldwork was completed before the start of the Coronavirus pandemic (Department for Business Energy and Industrial Strategy, 2019). We use the information from the LSBS and complement it with measures of the firm's partial technology stack.

4.2 Existing vs novel measures of firm-level technology adoption

A considerable amount of literature has been published using measures of technology adoption. At the firm level, this includes patents (Jaffe and Trajtenberg, 1999; Forman and Van Zeebroeck, 2019}, Research and Development (R&D) expenditures (Stoneman and Kwon (1996), Bessen, 2002) as well as survey-based measures (Circera et al., 2021). As patents are more likely to be filed and approved for larger firms, they do not seem an appropriate measure focusing on SMEs (Succurro and Costanzo, 2019). Survey-based measures within the UK, such as the LSBS, include questions on innovation within the firm but ask only very broadly whether a new process or product innovation has been adopted within the last three years.

Most surveys lack information on detailed measures of technology adoption, particularly on digital technologies for SMEs. For the US, the 2018 Annual Business Survey has included a new survey model covering technologies linked to the Fourth Industrial Revolution. Analysing the findings of the survey, Zolas et al. (2021) found that while some technologies, such as cloud computing, appear to be widely adopted, others, such as artificial intelligence, tend to be highly skewed, with only very productive firms having adopted them. For the UK, measuring innovation and technology adoption across firms in the UK is commonly done using the UK Innovation Survey (Battisti and Stoneman, 2010; D'Este et al., 2008; Crescenzi et al., 2015), which is part of the wider Community Innovation Survey and covers the topic of innovation in detail. However, the UK Innovation Survey is focused on larger firms, containing only firms with more than ten employees, leaving out a majority of firms within the UK. For smaller firms, selected surveys on digital technologies have been implemented, such as by Stankovska et al. (2016). They surveyed 66 SMEs in the UK, documenting the high usage of SMEs for some digital channels, particularly social media. To get information on a large sample of SMEs, the LSBS can be used. The LSBS

questions cover a large spectrum of SMEs' characteristics, with innovation being one aspect of many. Therefore, the information on which technologies were adopted is broad, which is why we complement the LSBS data with novel measures on digital technologies.

4.3 Novel measures of firm-level technology adoption

Accessing data from business websites provides novel insights on firm-level digital technology adoption. Digital technologies refer to the illustration of information in bits (Goldfarb and Tucker, 2019). The rationale behind many firms adopting digital technologies is to reduce costs, with the costs consisting of tracking, search costs, reproduction, verification and transportation and benefit from productivity gains (Goldfarb and Tucker, 2019). We complement the LSBS data with data from business websites using BuiltWith, which scrapes the websites getting data from the page body, cookies, and server headers. For every SME with a website, we get detailed information for 33 different technology categories and when they have been observed for the first time. This can, in contrast, provide more detailed information than surveys, allowing an understanding of the process of technology adoption at a more granular level. Having more information to complement existing measures of technology adoption provides a better evidence-based foundation for policymakers to adjust their existing policies, given that fostering digitalisation is at the centre of many policymakers aiming to foster economic growth. The goal is to provide a more accurate measurement of drivers of productivity and which technologies have a larger contribution to this, particularly in the wake of Brexit. We are not the first to use data on technology adoption of firms using information from their website and leveraging the platform Builtwith. Among others, Ragoussis and Timmis (2022) use it to analyse the digital response of firms during the COVID-19 pandemic, and Koning et al. (2022) test how experimentation affects start-up performance.

4.4 Linking LSBS data and business website data

The LSBS data includes the firm name and address if firms have agreed to data linkage, which is the case for 32,139 SMEs out of 39,177, making it possible to search for their website. To find and verify company homepages, we use a multistage process involving online searches on DuckDuckGo and fuzzy string matching. Initially, a search is conducted using the keywords “company name” and “UK company”. If the company name highly matches one of the resulting URLs, it is considered the homepage. If unsuccessful, a secondary search extends the search by adding the company’s address to the keywords. Upon finding a suitable URL in either stage, a verification step checks the company’s LSBS

provided address presence on the alleged homepage. If the address is found, the homepage is classified as "verified". We found 9,685 homepages, out of which 4,423 are verified. For the analysis, we only use the 4,423 SMEs where the homepage is classified as verified. We construct a balanced panel dataset following these firms for seven years, constructing a sample of 30,961 observations. One limitation from linking LSBS data and business websites is that we can only use time-invariant characteristics from the LSBS questionnaire, for example industry. As we have some firms participating in the LSBS in only one year, it is not possible to track changes stemming from the LSBS data over time.

4.5 Measuring technology adoption using SMEs' websites

As soon as we obtain the right URL of the business website, we can get the information about technology adoption from their website. We do this by using the tool BuiltWith, which is a database covering a large number of web technologies that enable us to determine which technologies a firm's website is using. Whenever a website is built with a certain technology, we assume that this firm has adopted this technology. For example, if we find the technology Shopify on a firm's website, we assume that a firm has adopted one technology in the e-commerce category. We can follow firms over time, as BuiltWith detects when a firm uses a technology for the first and the last time, providing information from 2000 onwards. With this information, we can create the partial tech stack of a firm, showing for each of the 33 categories the count of technologies.

Digital technologies related to e-commerce

Given that Brexit is a trade policy uncertainty shock, we are interested in technologies linked to e-commerce, with some of them more closely related than others, describing technologies that are trade-enhancing. This includes eight technology categories, including payment, javascript, secure sockets layer, language, analytics, shipping, e-commerce and content delivery network. Each category contains multiple specific technologies, and we count the number of technologies for each category by firm and year. Payment describes any technology that enables online payment, such as Visa or Mastercard. Javascript is used for interactive elements often linked to e-commerce, such as shopping carts or login information. A secure sockets layer is adopted for secure payment, enabling encrypted communication. Different languages are relevant for trading internationally, as well as shipping and e-commerce. In addition, analytic technologies are likely more relevant for firms that rely on their turnover mostly generated from their website. A content delivery network is also often adopted by firms using e-commerce, given that it is used for scaling up.

Limitations using technology adoption data based on business' websites

One main limitation of using indicators relying on web scraping business websites is the selection of firms into technology adoption. There are major differences across firms regarding whether they actually have a website and how advanced their website will be. Many firms do not have a website but only a Facebook page or other online representations of their business. Firms self-select into technology adoption, signifying that the sample will not be representative of the overall SME population but will rather over-represent firms that tend to adopt technology quicker and that are more productive, with a low or missing representation of less innovative firms. Moreover, we can only observe when a technology has been detected for the first and the last time. If a firm frequently removes and adopts a technology, we cannot observe it. However, it is not likely that firms will adopt and remove a technology frequently, given that this is an investment in time or capital. For a major shock like Brexit, we expect, though, that firms would reconsider the use of certain technologies. Additionally, we cannot observe whether the website was built internally or outsourced. For this paper, even if the development and maintenance of the website were outsourced, it might still be interesting to observe what happens after a major shock like Brexit. Since firms are likely to cut investment, this might also include reducing spending on website maintenance.

4.6 The Brexit vote

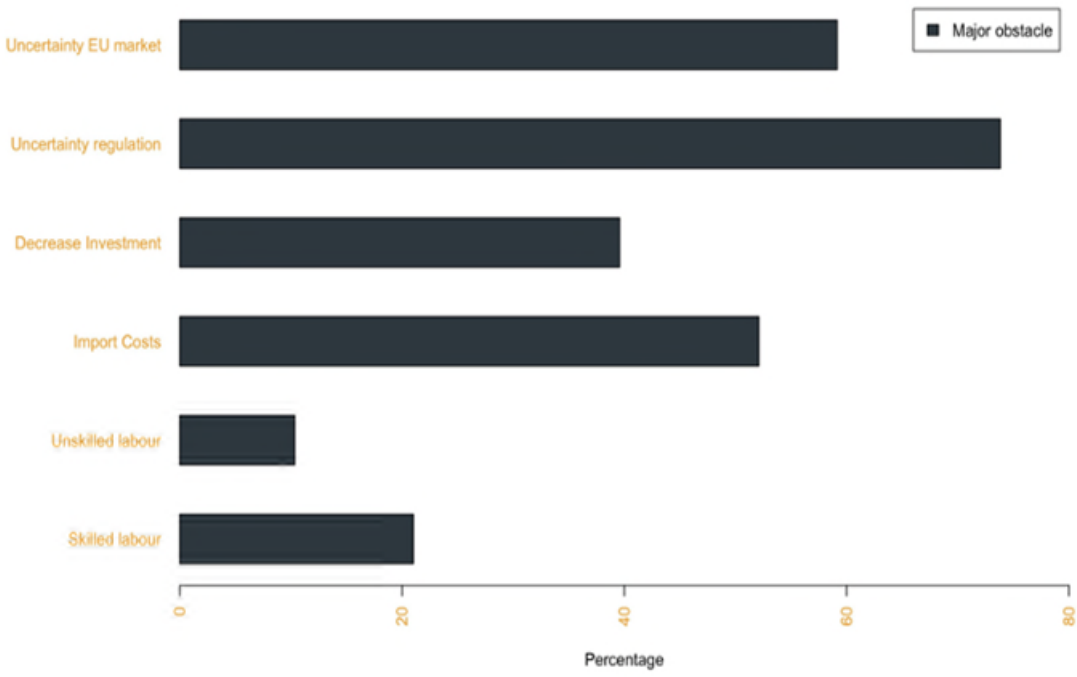
As we are also interested in how the effect on firms varies across space, we use two data sources linked to Brexit. The first one is the actual Brexit vote from the referendum on June 23, 2016. We get the data from Norris (2019), covering the calculated percentage of voters supporting the decision to leave the European Union at the constituency level. In addition to the actual Brexit vote, we gather data on the vote intention. We do so by accessing data from the British Election Study collected directly before the Brexit referendum. This applies to waves seven and eight of the 2014-2023 British Election Study. Both are online surveys collected between April and May (wave seven) as well as May and June 2016 (wave eight). The respondents were asked about their voting intention, being posed the following question "Should the United Kingdom remain a member of the European Union or leave the European Union?". We merge the respondents of these two waves, keep the answer of respondents only once if they have participated in both waves and calculate the share of the intention to vote for "Leave" at the NUTS-3 level.

5. DESCRIPTIVES

5.1 Brexit-related obstacles

The Brexit referendum affects SMEs in multiple ways, but mostly through trade with the EU and uncertainty. In 2017, SMEs participating in the LSBS were surveyed about their views on Brexit as a significant hindrance. If they responded affirmatively, they were further asked about the specific factors they considered obstacles. Figure 1 shows the percentage of SMEs concerned about each relevant factor as a percentage of all SMEs that perceived Brexit as a major hurdle in 2017. Uncertainty related to the EU market, uncertainty linked to regulation and an increase in import costs are most commonly viewed as the major obstacles related to Brexit, with more than 50% indicating so. The results of the survey support empirically that trade policy uncertainty compiles the major shock for SMEs.

Figure 1: Type of Brexit-related obstacles, weighted, 2017

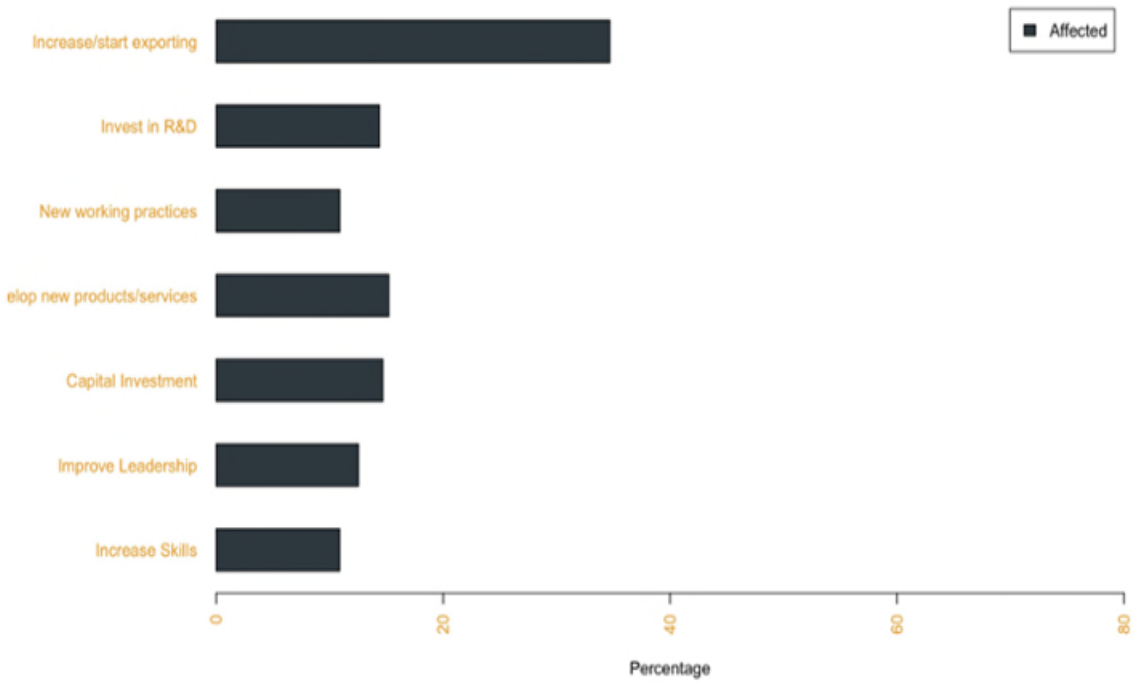


5.2 Plans of SMEs affected by the Brexit referendum

In addition to asking how SMEs perceive Brexit, they are also asked what plans have been affected. From 2017 onwards, SMEs of cohort B in the LSBS were surveyed about whether their plans for the next three years have been affected by Brexit. In the survey, the following question is posed: “Have any of these plans been affected by the UK exit from the EU? IF YES: Which plans?” and a set of answers is provided. The answers are coded as a binary

variable. We use the first year where the question is asked in 2017 to provide an overview of how SMEs have been affected1. In Figure 2, the percentage of those SMEs that indicated that their plans had been affected by Brexit for different relevant answers are shown. It shows that "increasing export sales or begin selling to new overseas markets" is the most commonly indicated, with around 35% of SMEs whose plans have been affected related to exporting and selling overseas. Launching a new product and services (15.2%), capital investment (14.7%) and investing in R&D (14.4%) are the most frequent plans disrupted due to Brexit after exporting. Increasing skills (10.9%) and new working practices (10.9%), in contrast, are the least indicated by those SMEs whose plans have been affected.

Figure 2: Type of plans affected by Brexit, weighted, 2017



5.3 Average trends in digital technology groups

For e-commerce-related technologies we plot the average changes per group between 2013 and 2019. The EU-dependent treatment group consists of SMEs that have indicated trading with the EU at least once. So, if firms in our sample have participated in the LSBS twice and indicated trading with the EU only in one year, they will be assigned to the

[1] Results are weighted by the "Brexit weight", which has been introduced in addition to the cross-sectional and longitudinal weight due to some inconsistencies related to the distribution of the survey

treatment group. SMEs that have never indicated to trade with the EU, in contrast, are assigned to the control group. We have excluded shipping and language, given that only a very small number of SMEs possess these, substantially reducing the sample in the analysis to a few hundred observations. For e-commerce, we come to the conclusion that the parallel trends assumption does not hold, as shown in Figure 14 in the appendix. For the other five technologies - payment, secure sockets layer, analytics, javascript and content delivery system - we find that before the treatment, the trends appear to move in parallel. We use 2013 as the first year, given that in the previous years the mean and the change have been centred around 0. For e-commerce, in contrast, we find a drop in the adoption from 2014-2015 in the treatment group, whereas the control group observes an increase. For this reason, we cannot assume that the parallel trends assumption is met and thus we exclude e-commerce from the following analysis. For most of the five digital e-commerce-related technologies, we see an immediate drop after the treatment, in 2017. While before 2016, the average change in the treatment group was mostly above that of the control group, it dropped below its comparison for the first time after the Brexit referendum.

Figure 3: Average trends secure sockets layer by group, 2013-2019

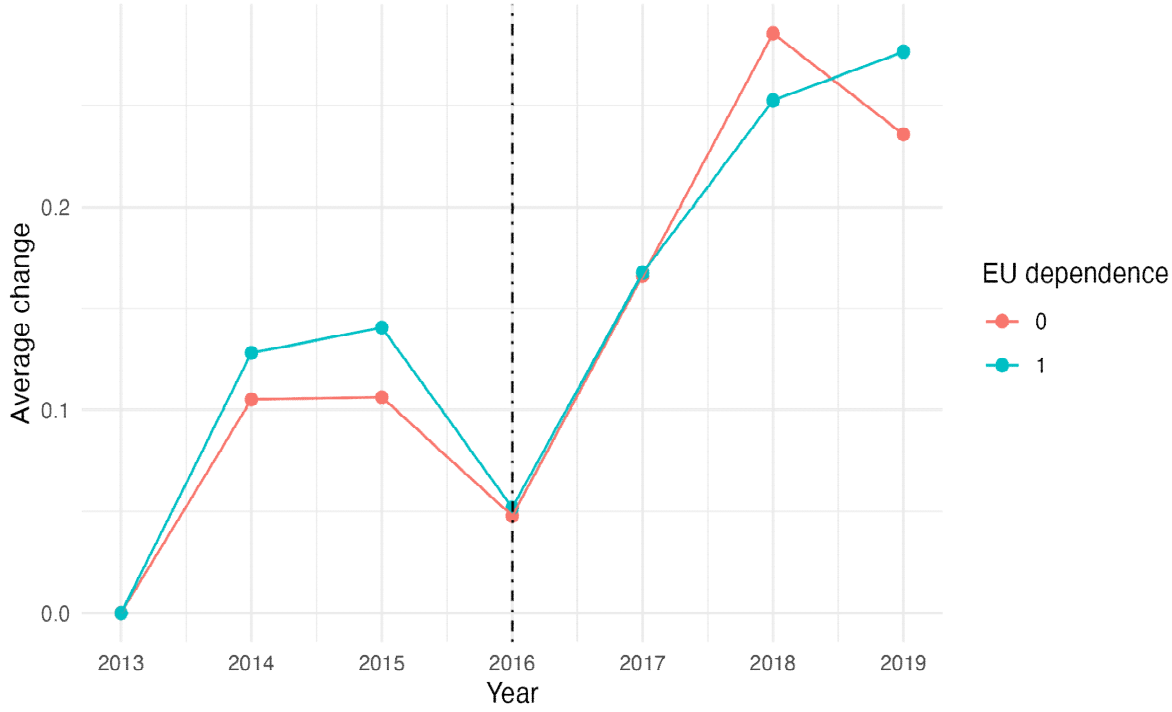


Figure 4: Average trends analytics by group, 2013-2019

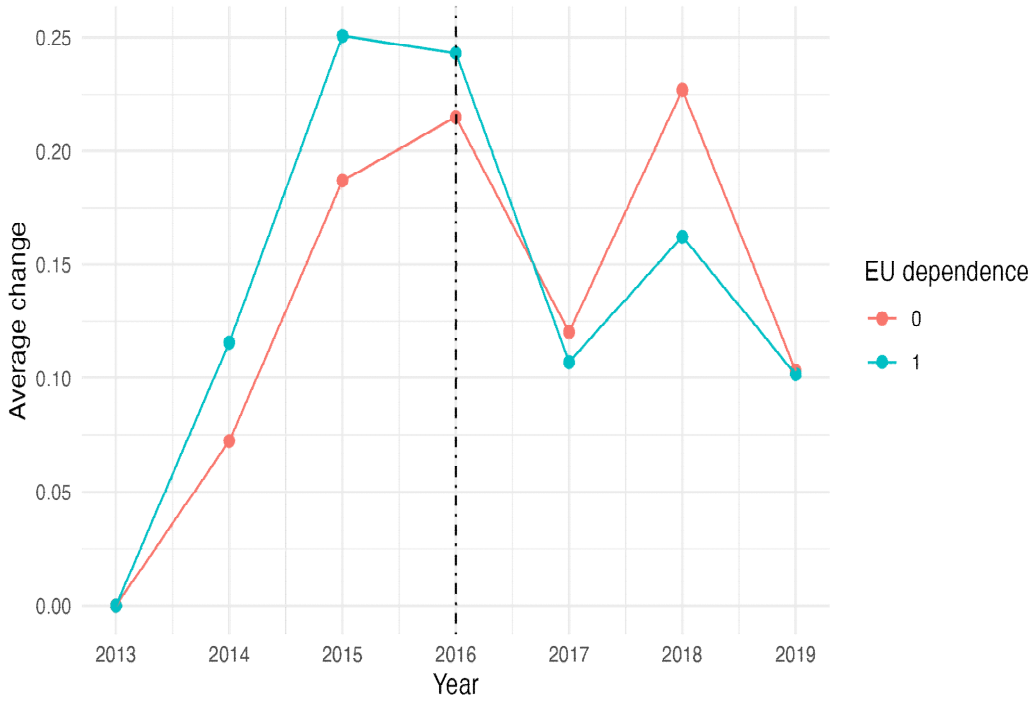


Figure 5: Average trends payment by group, 2013-2019

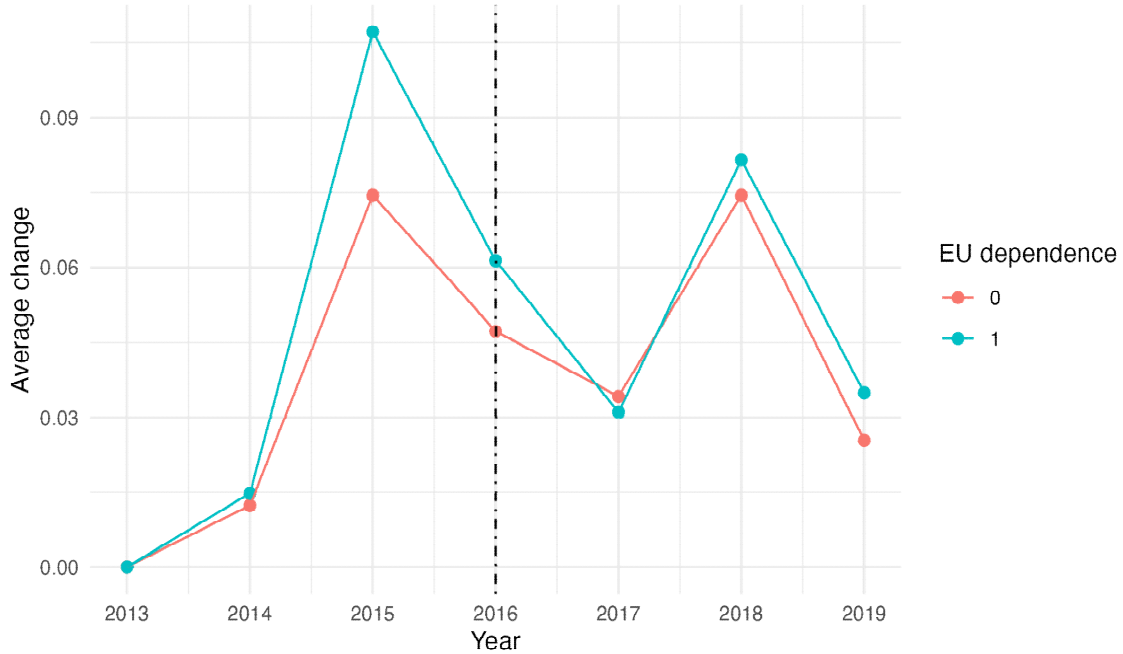


Figure 6: Average trends javascript by group, 2013-2019

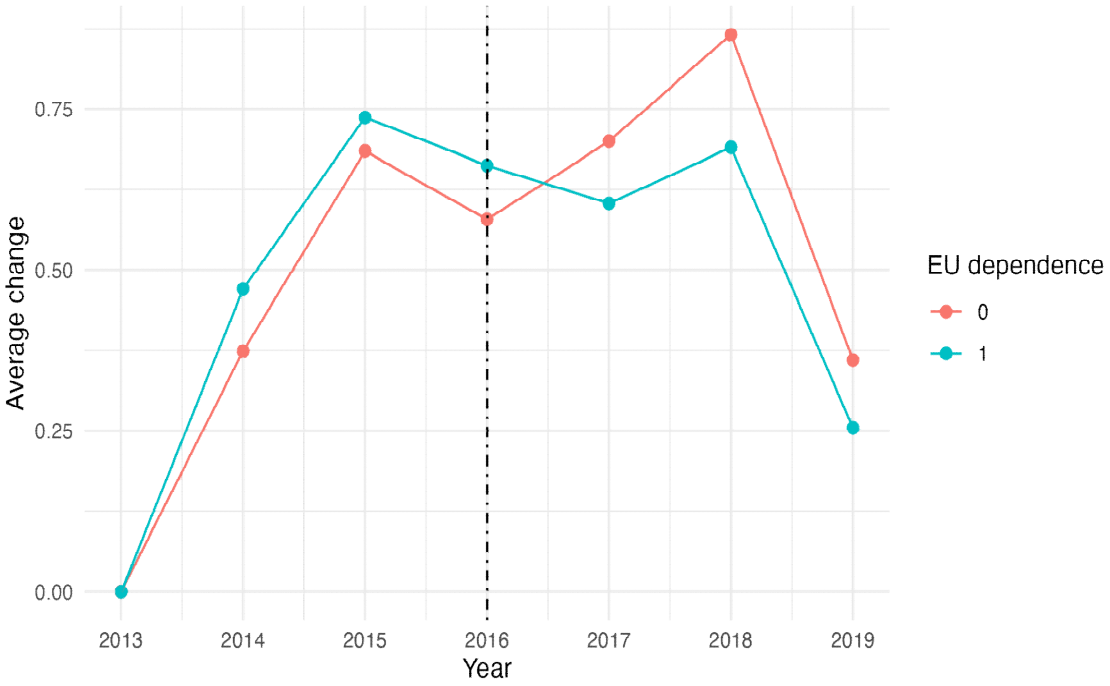
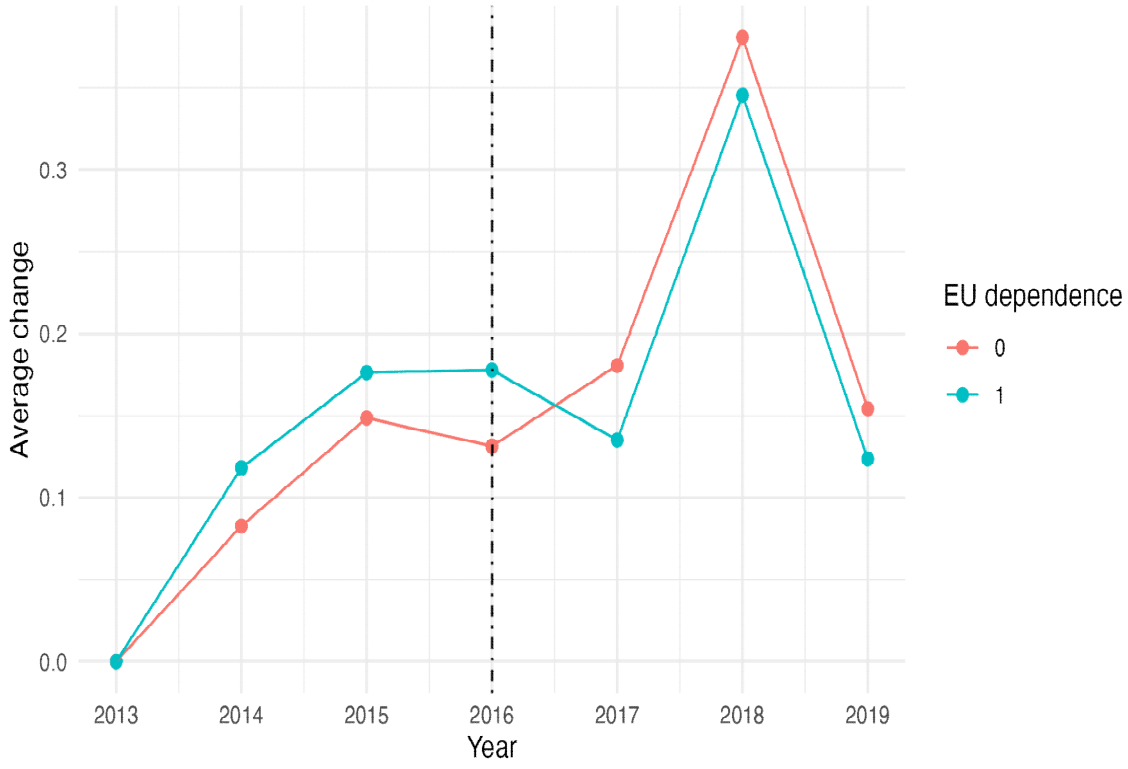


Figure 7: Average trends content delivery network by group, 2013-2019



6. METHODOLOGY

We study the effect of Brexit on firm-level performance, focusing on how digital technology adoption has been affected. We exploit the Brexit referendum as a trade policy uncertainty shock to firms that trade with the EU, compared to those that do not trade with the EU or do not trade at all.

6.1 Difference-in-differences method

Previous papers have used a difference-in-differences approach to estimate the effect of Brexit on different outcome measures. The effect on trade has been studied, among others, by Crowley et al. (2020), Kren and Lawless (2022) and Freeman et al. (2022). Kren and Lawless (2022) find that UK-EU trade has significantly decreased, using the trade between the EU and every other nation in the world as a control group. Freeman et al. (2022), in contrast, find no evidence on UK-EU trade before the Trade and Cooperation Agreement, using as control group trade between the UK and every other nation in the world. Bloom et al. (2019) estimate the effect on investment and productivity. We study the effect of Brexit on firm-level performance, focusing on how digital technology adoption has been affected. We exploit the Brexit referendum as a trade policy uncertainty shock to firms that trade with the EU, compared to those that do not trade with the EU or do not trade at all. We use a standard 2x2 difference-in-differences equation in the following form:

$$y_{it} = \beta\ EU_i * Post_t\ + v_i + v_t + \varepsilon_{it}$$

where y_{it} describes the count for the digital technology i in year t related to e-commerce, EU_i is a dummy that takes the value one if a firm trades with the EU and 0 otherwise, $Post_t$ a time dummy taking the value 1 for all years after 2015, v_i are firm fixed effects, v_t are year fixed and ε_{it} the error term. We use the eight technologies related to e-commerce described in section 4.5. Firm fixed effects are used to control for time-invariant heterogeneity, including sector, age, and size, which all are major predictors for adopting technology. As the dependent variable is a count variable, we use a Poisson model to estimate the effects.

6.1.1 Identification assumptions

Given the difference-in-differences approach, causal identification relies on the parallel trends assumptions. Thus, in the absence of treatment, the outcome of the treatment group and the control group would have moved in parallel. In this case, the average changes in

digital technology adoption of the group of SMEs that trade with the EU have moved in parallel with the average change of the control group. In section 5.3, we plot the average outcome changes per group between 2013-2019 to show that the changes of both have been moving in the same direction before the treatment. In addition, we plot the dynamic treatment effects in Figure 15 in the appendix, including the pre- and post-treatment periods. It shows that none of the pre-treatment coefficients is significantly different from 0, which further supports that there are no differences in the trend for the two groups prior to the treatment and that no anticipation effects are present.

A challenge to causal identification could stem from other shocks affecting technology adoption, which might lead to the identification of another shock or an interaction with it. One of these shocks could be the Covid-19 pandemic. Previous research by Riom and Valero (2020) has shown that Covid-19 has impacted many firms to adopt remote work and has accelerated digital tech adoption for more than 60% of the UK firms surveyed. To disentangle the effect of Brexit, we exclude the last year of the transition period, before the UK–EU Trade and Cooperation Agreement was signed. Thus, the post-treatment period lasts from 2017-2019, excluding the period from 2020 onwards due to Covid-19. Additionally for this draft, we assume that firms did not start trading as a response to Brexit, given that firms have responded with a decrease in trade after Brexit. Exporting to other foreign markets is costly and appears rather unlikely given a major shock like Brexit. However, we plan to conduct further checks on this.

6.1.2 Brexit as Geographic Surprise Shock

We also estimate how differences in regional voting patterns affect SMEs' digital technology adoption. We do so by using Brexit as geographical surprise shock (GSS), measured by the differences between the actual Brexit vote and the survey-based expectations per region j:

$$GSS_j = Brexitvote_j - E(Brexitvote_j)$$

The intuition is that in some regions, it was much more surprising than in others that the votes towards "Leave" actually received the majority. In London, for example, it was surprising and unexpected that the UK would actually leave the EU, while in others, it was less so. This strategy thus exploits the inter-regional differences between expectations and the actual Brexit vote to identify the effect of Brexit on firm-level performance, particularly technology adoption. This identification takes into account that regions where citizens were

more likely to vote for "Leave" have been suffering from economic decline (Carreras, 2019) and, thus, from lower productivity. As the Brexit vote is endogenous to the productivity of regions, which is a main driver in the technology adoption of firms and firm performance, we deduct the previous expectations. We aim to do so by deducting the endogenous part linked to productivity and economic decline in the form of expectations towards Brexit and using the exogenous variation, defined as the variation left unexplained by regional socioeconomic observables. We estimate difference in-differences equations of the following form:

$$y_{ijt} = \beta \left(GSS_j \, Post_t \right) + v_i + v_j + v_t + \varepsilon_{ijt}$$

with y_{ijt} being the count for the digital technology i in year t related to e-commerce, GSS_j is the Geographical Surprise Shock, which is the difference between the expected local vote for Brexit and actual local Brexit vote in region j at NUTS-3 level, $Post_t$ is a dummy that takes the value of 0 before 2016 and 1 after. v_i are firm fixed effects, v_j are region fixed effects and v_t are year fixed effects.

7. RESULTS

7.1 Main Results: e-commerce-related digital technologies

The table below shows that SMEs which trade with the EU experienced, on average, a decline in all five e-commerce-related digital technologies compared to the comparison group and before the Brexit referendum. For payment, secure sockets layer, analytics and javascript, the decline is significant at the 5% level. The coefficient of the content delivery network is negative but not statistically significant. The dynamic treatment effects for all five digital technology groups are shown in Figure 15, showing that the pre-treatment coefficients are insignificant and most of the post-treatment coefficients are significant, with an increasing trend until 2019. The effect intensifies until 2019, suggesting a gradual response by SMEs adjusting to the shock.

Dependent Variables:	Payment	Secure Layer	Analytics	Javascript	Content Del. Net.
Model:	(1)	(2)	(3)	(4)	(5)
Variables					
EU trade*post					
	-0.165**	-0.135**	-0.199***	-0.154***	-0.068
	(0.076)	(0.053)	(0.042)	(0.041)	(0.061)
Fixed-effects					
Firm					
	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
Fit statistics					
Observations					
	8,540	20,594	15,820	21,301	17,080
Squared Correlation	0.60438	0.44457	0.59391	0.65514	0.63701
Pseudo R^2	0.25204	0.22088	0.24086	0.40801	0.33278
BIC	24,637.7	68,400.0	60,353.7	114,637.6	56,924.2

Signif. Codes: ***: 0.01, **: 0.05, *: 0.1
Clustered (firm) standard-errors in parentheses. Different numbers of observations are explained by the exclusion of firms that never adopt a given technology.

These findings align with other studies showing that firms have reduced exports (Crowley et al., 2018; Brown et al., 2019) after the Brexit referendum, which is likely also reflected in e-commerce-related digital technologies. Given that SMEs reduce trade, they are likely to respond by also removing or reducing technologies that are needed to trade with. The response intensifies over time, which can be explained by trade policy uncertainty remaining high for firms until 2019, letting firms adjust their digital behaviour three years after the Brexit referendum. Until then, it was not clear whether there would be a “hard” or “soft” Brexit, leaving firms in trade policy uncertainty. Our results suggest that SMEs have responded to this trade uncertainty shock by reducing trade-enhancing technologies over these three years after the Brexit referendum, compared to SMEs that do not have any direct links to the EU.

7.2 Results by Sector: Digital technologies related to e-commerce

The table below looks at the effect by industry (SIC1DIG), demonstrating that multiple sectors drive the overall effects. This is the case for all technology groups, where different sectors are relevant for explaining the overall decline. These include typical sectors for the trade of goods, such as manufacturing or retail, but also for the trade of services, like professional and scientific services. For the category payment, we show a significant decline in the primary sector, other services as well as wholesale and retail, with the largest coefficient in other services. Regarding secure sockets layer, we find that in the sectors education, manufacturing, wholesale and retail, and information and communication we can observe a significant decline, with the largest changes observed in the education sector. For analytics, we find a significant decrease in primary, administrative and support, manufacturing, wholesale and retail, accommodation as well as professional and scientific services, with the largest change in the primary sector. The overall decline in javascript is driven by the primary sector, manufacturing, transport and storage, information, and communication as well as professional and scientific, also showing the largest decline in the primary sector. For the content delivery network category, we find that the overall decline stems from the sectors education, accommodation and food as well as professional and scientific services, with the largest decline in the education sector. Thus, we find that the significant reduction in e-commerce-related digital technologies stems from the decline of technologies in multiple sectors, which vary by technology class and in magnitude, with the education, service and the primary sector playing a major role.

Dependent Variables:	Payment	Secure Layer	Analytics	Javascript	Content Del. Net.
Model:	(1)	(2)	(3)	(4)	(5)
Variables					
Treat*Primary	-0.662**	0.107	-0.506**	-0.506*	-0.189
	(0.319)	(0.360)	(0.253)	(0.276)	(0.311)
Treat*Admin./Support	-0.276	-0.194	-0.291**	0.016	-0.133
	(0.192)	(0.176)	(0.135)	(0.131)	(0.161)
Treat*Education	0.084	-0.501*	0.601	0.243	-0.598**
	(0.453)	(0.283)	(0.434)	(0.302)	(0.300)
Treat*Health/Social Work	-0.394	-0.120	0.319	0.145	-0.070
	(0.403)	(0.398)	(0.396)	(0.269)	(0.288)
Treat*Arts/Enter.	-0.337	-0.174	-0.192	0.142	-0.381
	(0.311)	(0.266)	(0.253)	(0.380)	(0.336)
Treat*Other service	-0.742**	-0.089	-0.202	0.065	0.109
	(0.358)	(0.451)	(0.218)	(0.215)	(0.184)
Treat*Manufacturing	-0.133	-0.225**	-0.220***	-0.193***	0.061
	(0.137)	(0.090)	(0.064)	(0.072)	(0.133)
Treat*Construction	-0.094	0.140	0.135	0.068	0.438
	(0.334)	(0.250)	(0.216)	(0.191)	(0.334)
Treat*Wholesale/Retail	-0.210*	-0.178*	-0.148**	-0.122	-0.098
	(0.112)	(0.091)	(0.071)	(0.077)	(0.115)
Treat*Transport/Storage	0.455	-0.140	-0.087	-0.243*	-0.025
	(0.580)	(0.177)	(0.174)	(0.144)	(0.171)
Treat*Accommodation/Food	0.239	-0.015	-0.194	0.001	-0.380**
	(0.398)	(0.239)	(0.164)	(0.145)	(0.192)
Treat*Inform./Comm.	-0.372	-0.275**	-0.272**	-0.277**	0.082
	(0.287)	(0.121)	(0.125)	(0.132)	(0.244)
Treat*Financial/Real Estate	-0.162	0.558	-0.257	-0.301	0.024
	(0.413)	(0.473)	(0.191)	(0.204)	(0.262)
Treat*Professional/Scientific	0.056	0.022	-0.227**	-0.234**	-0.281**
	(0.183)	(0.142)	(0.095)	(0.101)	(0.127)
Fixed-effects					
Firm	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
Fit statistics					
Observations	7,371	17,892	13,811	18,445	14,805
Squared Correlation	0.61190	0.44794	0.58992	0.65830	0.64222
Pseudo R^2	0.25246	0.22009	0.23605	0.40645	0.33492
BIC	21,241.6	28,59,241.3	52,581.6	99,153.8	49,142.2

Signif. Codes: ***: 0.01, **: 0.05, *: 0.1
Clustered (firm) standard-errors in parentheses. Different numbers of observations are explained by the exclusion of firms that never adopt a given technology.

7.3 Other technologies

In addition to the effect on trade-enhancing technologies, we also look at other technologies that may have been significantly impacted by the Brexit referendum. This is highly relevant to understand whether SMEs are not only responding through the trade channel but whether this trade policy uncertainty shock has had a wider impact beyond trade. Our results suggest that this is the case, and in the table below, we show the digital categories where we find a significant effect. For multiple categories, we find a negative and significant effect for technologies that are not classified as e-commerce. In response to uncertainty from the policy shock, SMEs reduce or adopt fewer multiple digital technologies, including media, content management systems, framework, hosting, mobile, web server and name server.

Dep. Var.:	Media	Content MS	Framework	Hosting	Mobile	Web Server	Name Server
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables							
EU trade*post	-0.324**	-0.100*	-0.138***	-0.147***	-0.196***	-0.144***	-0.195***
	(0.133)	(0.058)	(0.043)	(0.040)	(0.068)	(0.033)	(0.042)
Fixed-effects							
Firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics							
Observations	4,473	15,246	17,899	22,351	18,284	22,253	16,289
Sq. Corr.	0.49014	0.49862	0.50910	0.47799	0.66084	0.49089	0.42823
Pseudo R^2	0.21126	0.22576	0.19403	0.17533	0.35746	0.15366	0.12347
BIC	11,641.1	50,373.4	61,848.7	72,028.2	60,724.1	77,810.1	48,433.8

Signif. Codes: ***: 0.01, **: 0.05, *: 0.1
Clustered (firm) standard-errors in parentheses. Content MS refers to Content Management System. The table presents the effect of other technologies that are not e-commerce related. Different numbers of observations are explained by the exclusion of firms that never adopt a given technology.

Some of these technologies can be regarded as basic technologies, suggesting that SMEs are removing basic technologies that are needed for the functioning of the website at all. One example would be name server; websites would only be useful if they can be found using a human-readable name, not via the IP address. SMEs might remove these technologies or adopt them less as they stop using them temporarily, compared to before the Brexit referendum. Therefore, our results suggest that Brexit has had a major impact beyond the trade channel, removing basic technologies needed for the functioning of a

website. These results are also in line with what was found in previous literature. Given that the Brexit referendum has had a major impact not only on trade but also on investment productivity and innovation in general, we would expect firms to be affected to a larger extent.

7.4 Brexit as Geographical Surprise Shock

We also run the estimations for Brexit as Geographical Surprise Shock, as described in Section 6.1.2, using the same e-commerce-related technology categories as in the baseline results. We present the results in the appendix, in section 9.9. We do find a positive effect for all five categories, but the estimated coefficient magnitude tends to be small and insignificant. We, therefore, conclude that Brexit as Geographical Surprise Shock did not have a substantial impact on digital technology adoption of SMEs in the UK.

8. DISCUSSION AND NEXT STEPS

We study the impact of the Brexit referendum on the digital technology adoption of UK SMEs from 2013-2019. We exploit the Brexit referendum as a trade policy uncertainty shock, using a difference-in-differences methodology to examine the response of SMEs engaged in trade with the EU. The Brexit referendum increases potential future trade costs and casts uncertainty over firms that depend on the EU for import and export activities. We link existing survey measures to novel data sources on digital technology adoption from firms' websites. This integrated approach provides more detailed and timely measures to better understand how SMEs respond to a severe policy shock. Given that SMEs are the largest group of private firms and recognising the positive correlation between digital technology adoption and productivity gains, it is essential to understand the response to such a major shock. However, evidence is missing on this effect when it comes to digital technology adoption, a key component of productivity growth. Our study contributes to bridging this knowledge gap by developing novel measures for technology adoption, leveraging the ever-increasing volumes of data available from businesses' websites.

We find that SMEs react to this shock by decreasing their use of e-commerce-related technologies, as well as other digital technologies. In light of the uncertainty shock imposing higher future trade costs, SMEs appear to decrease e-commerce technology from the following groups: payment, secure sockets layer, analytics and javascript. The effects are observed across sectors, including those typically linked to the trade of goods but also those of services: the primary sector, education, manufacturing, retail, professional services, and

information. In addition, we also find a significant decrease in other technologies that we do not classify as e-commerce related, with some of them being basic technologies for the functioning and quality of a website. This is in line with previous research, showing that the Brexit referendum has had a substantial impact on UK firms, who respond by decreasing investment in technology and innovation, leading to declines in exports and productivity. Our research supplements the existing literature by shedding light on how Brexit has influenced SMEs' adoption and use of productivity-enhancing digital technologies. We identify a pervasive effect and point out the likely mechanisms at play which extend beyond trade channels.

There are multiple limitations linked to this study. First, while we enhance currently existing measures of digital technologies, we cannot measure the full tech stack SMEs may use, relying instead on the technologies that can be observed in firms' websites. One area for future research would be to expand in this direction by gathering further data sources and using supervised learning approaches to estimate full technology stacks firms may use over time. In this first version of the paper, we assume our observed technologies to be equally relevant for each technological category, ignoring the fact that in practice certain software applications may be more relevant than others for our population of interest. Extension work will seek to improve the rudimentary technology indicators shown here provide measures of digital technology adoption that account for this heterogeneity.

In addition, we plan to collect more pre-Brexit data at the firm level, which should help build a comprehensive set of covariates for the sample SMEs before the shock to expectations stemming from Brexit. This will be accompanied by additional analysis including, for example, results based on the sector-specific degrees of digitalisation. Additionally, we also plan to greatly enhance the set of robustness checks we run, particularly those concerning the assumptions linked to the difference-in-differences approach. On the other hand, due to the onset of the Covid-19 pandemic, the scope of our analysis ends in 2019, implicitly limiting our ability to observe the fallout of the actual outcome of the Brexit vote. Despite these limitations and given that this is still work in progress, we believe that with this research, we fill the knowledge gap by providing insights into which firms and digital technologies have been most impacted by the Brexit referendum. These findings should prove useful for policymakers, empowering them with the information needed to design and implement effective measures that mitigate some of the detrimental effects on firms.

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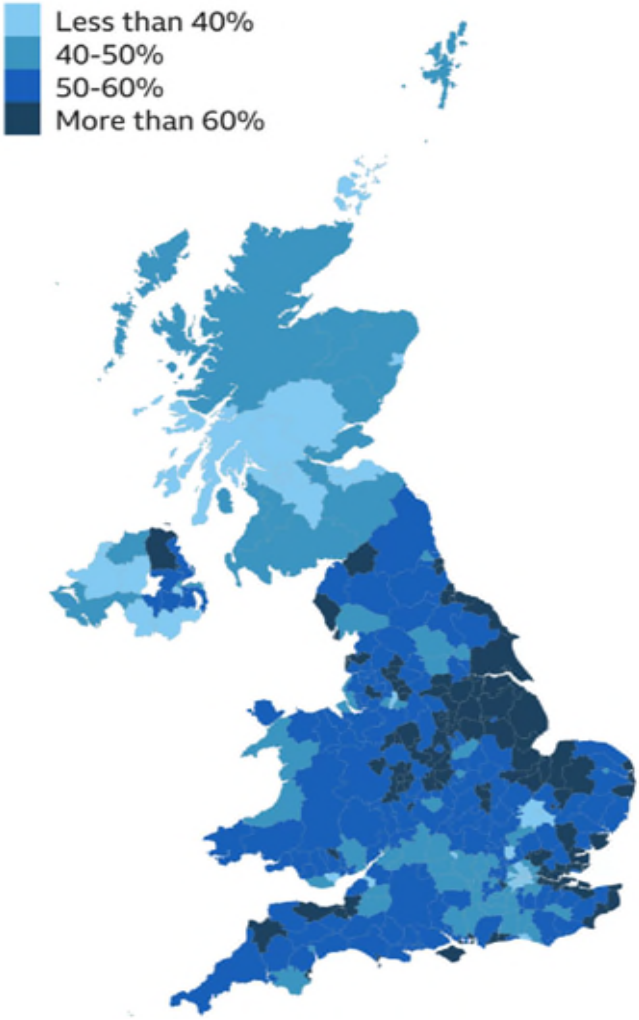
APPENDIX

9.1 Spatial dimension of the Brexit vote

We also show the map of the spatial differences in the Brexit vote at the regional level. It clearly shows a gap between voting patterns, with constituencies in Scotland and London being clearly more in favour of remaining part of the EU, whereas the East Midlands and the South West of England voting for the UK leaving.

Figure 8: Brexit vote towards "Leave"

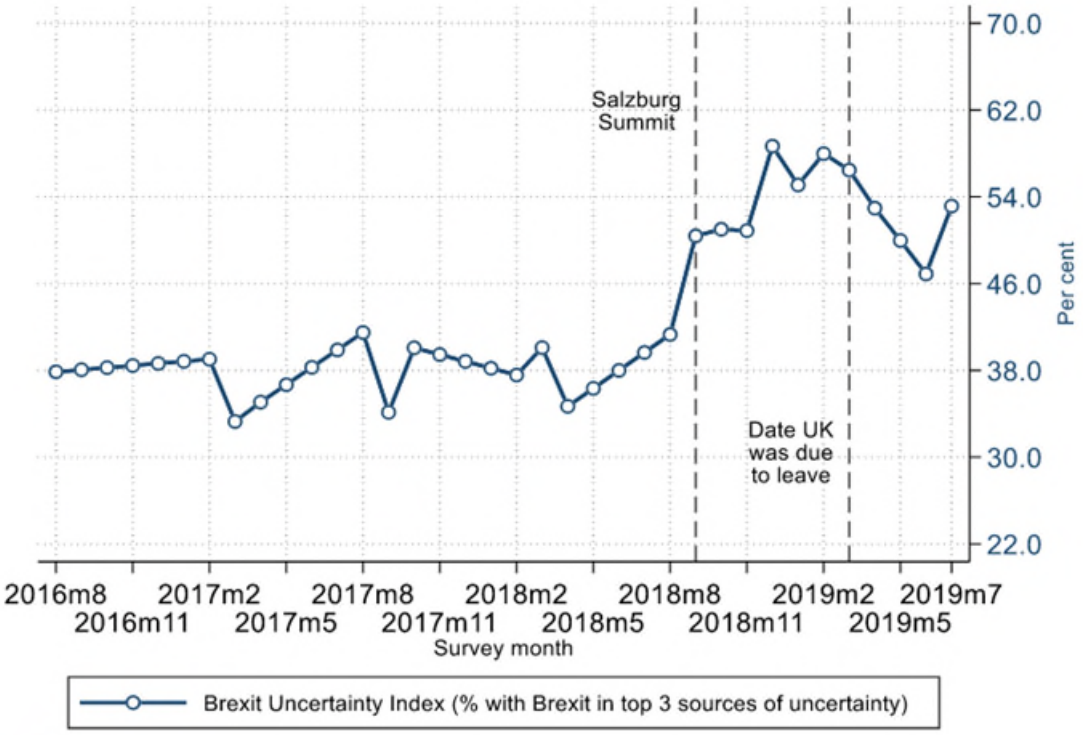


Source: BBC (2016)

9.2 Development of the Uncertainty Index

Figure 9 plots the uncertainty index from 2016-2019, measured from survey data stemming from UK firms (Bloom et al., 2019). It shows that uncertainty remained high until three years after the Brexit referendum and increased substantially at the time that the UK was supposed to leave the EU and before it actually left.

Figure 9: Development of the Brexit Uncertainty Index



Source: Bloom et al. (2018)

9.3 Brexit-related questions in the LSBS

The LSBS asks firms about their main obstacles every year, with Brexit as one of them. In the survey questionnaires from 2016 onward, questions around Brexit have been included. These range from very general questions such as whether Brexit is perceived as a major obstacle, to more specific elements, like what aspects of Brexit they are concerned about and how their plans have been affected. Not all of these questions were already asked in 2016; some have been introduced in 2017, such as whether their plans have been affected, and some are only available in 2017, such as whether they feel prepared for Brexit. Also, not all questions have been asked to all firms, some of them have only been asked certain

cohorts, such as whether their plans have been affected. A short overview of information on Brexit is shown in the table below.

Identifier	Question	Years asked
G2	Which of the following would you say are major obstacles to the success of your business in general?: UK exit from the EU	2016-2021
R9	Overall, how beneficial or detrimental would UK exit from the EU be to your business? (scale 1-5)	2016-2021
G8	Which of these, if any, are the obstacles that your firm faces because of the UK's forthcoming exit from the EU?	2017-2021
R8a	Have any of these plans been affected by the UK exit from the EU? IF YES: Which plans?	2017-2021
R8b	How has the scale of these plans been affected by the UK exit from the EU? For each that I read out, please tell me whether they have been scaled down or scaled up, or do they remain at the same level?	2017-2021
R8c	How has the timing of these plans been affected? For each that I read out, please tell me whether they have been brought forward, pushed back or is the timing unaffected?	2017-2021
R10	How prepared do you feel your [ANSWER AT A-2] is currently for the UK's exit from the EU? (scale 1-5)	2017

9.4 Brexit as an obstacle for SMEs and particularly exporters

The aim is to show whether Brexit was perceived by SMEs as a major obstacle and to what extent. To get a general picture that is representative for the SME population, we use the specific questions introduced to the LSBS questionnaire in 2016 inquiring whether the UK leaving the EU is seen as a major concern. For every year, we count the number of firms indicating that Brexit is a major obstacle and weigh it with the cross-sectional weights. As there are substantial differences between different types of firms, we also show the extent and development of Brexit being perceived as an obstacle. We plot the results for all SMEs and exporters over time, which are shown in Figure 10. The figure for all SMEs shows that the percentage of firms perceiving Brexit as a major obstacle increased over the observation period, reaching its peak in 2017. In 2016 the concern tends to be the lowest with a substantial rise in 2017. In 2018 and 2019 the concern for Brexit as a major obstacle slightly declines, remaining at a higher level than in 2016. The figure for exporting SMEs, Figure 11, shows a similar trend, but at an elevated level, clearly pointing out that the concern of exporters towards Brexit as a major obstacle is substantially higher.

Figure 10: Percentage of SMEs SMEs that perceive Brexit as major obstacle, obstacle, weighted, 2016-2019

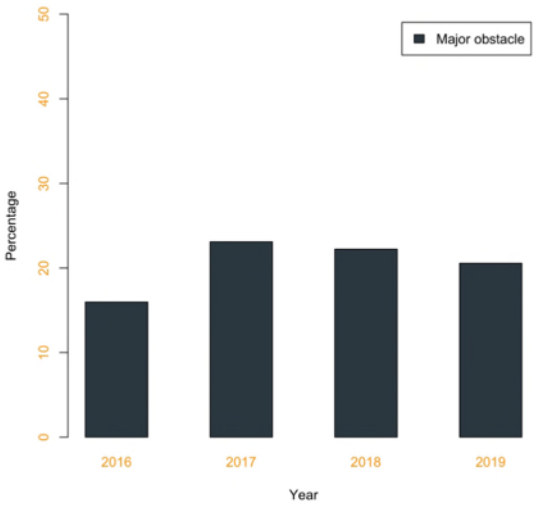
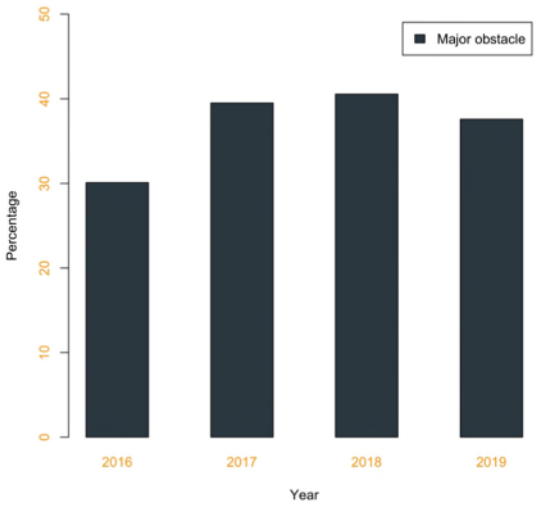


Figure 11: Percentage of exporting that perceive Brexit as major weighted, 2016-2019



9.5 Summary statistics

We compare the sample we analyse to the representative SME population. We find that our sample tends to include more SMEs that are larger in size and are more likely to export. Looking at employment as a firm size indicator, it becomes clear that our sample consists of larger firms. We use four categories, including no employees, micro (1-9 employees), small (10-49 employees), and medium (50-249). In our sample, most firms fall into the category of micro and small, making up around 36% and 33% respectively. Firms with no employees account for 17% and medium enterprises for 14%. Our sample includes a substantially smaller percentage of firms with no employees. In 2015, firms without any employees were making up 76% (Department for Business Energy and Industrial Strategy, 2016). In addition, SMEs in our sample are more likely to export goods or services. Below, we show that in our whole sample, approximately 26% have exported goods and services outside of the UK in the last year, which is notably higher than the representative SME population in the LSBS. In 2016, for example, around 16% of the UK SME population exported goods or services outside of the UK.

Figure 12: Percentage of firms by of employment size, whole sample

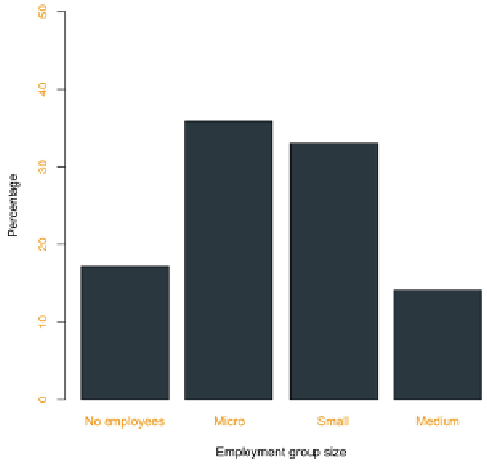
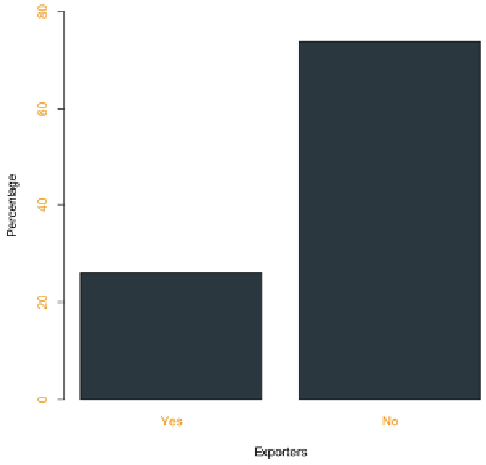


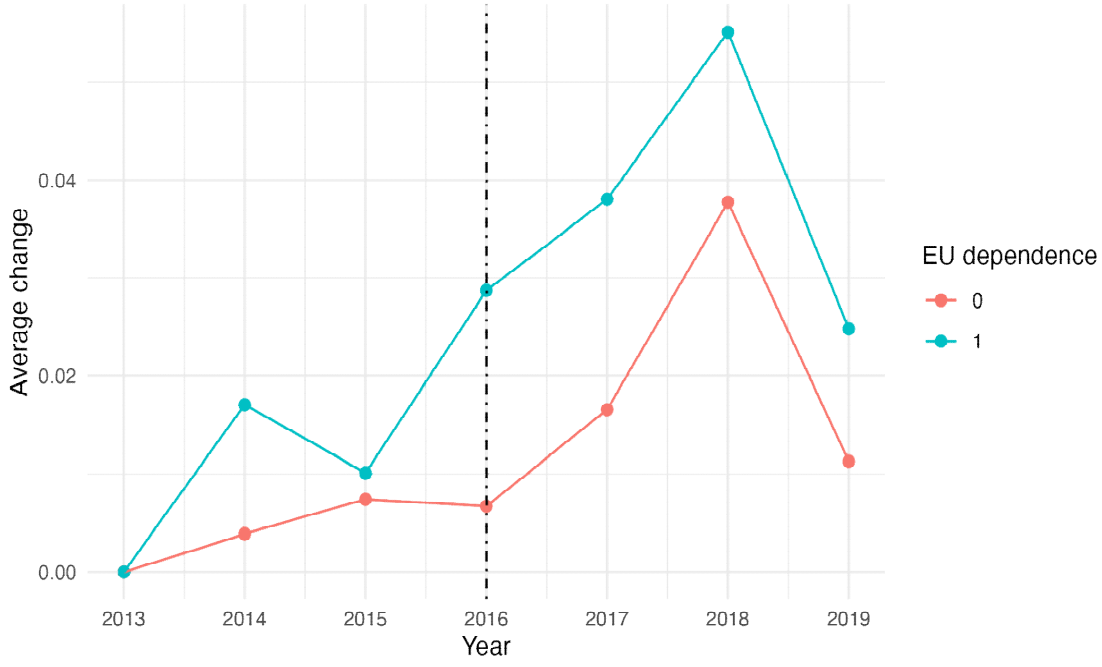
Figure 13: Percentage of exporters goods and services, whole sample



9.6 Average changes in e-commerce per group

We also show the average changes by group for e-commerce technologies over time. In contrast to the other five technologies, we do not find that trends before the treatment are moving in parallel. Thus, we have excluded e-commerce as technology from the main analysis.

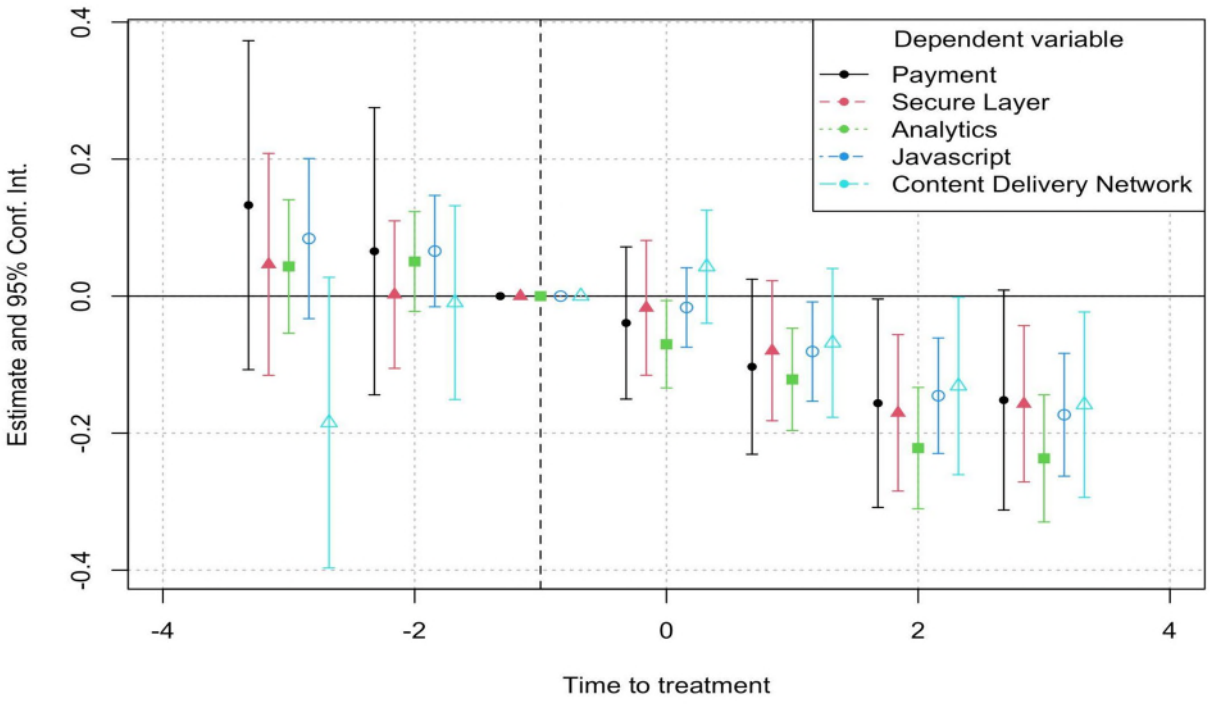
Figure 14: Change in e-commerce technology per group, 2013-2019



9.7 Main Results: Dynamic treatment effects

The coefficient plot below shows the dynamic treatment effect for all five dependent variables relative to one year before the treatment. It shows the pre-treatment coefficients, which are all not statistically significant, and the post-treatment coefficients, which are gradually increasing in magnitude. While in 2016 most of the coefficients are not statistically significantly different from 0, we see that the effect size increases with every year, becoming significant for nearly all e-commerce-related technologies in 2019. This speaks for the effect intensifying over time which is likely stemming from the uncertainty that remained high until the end of 2019.

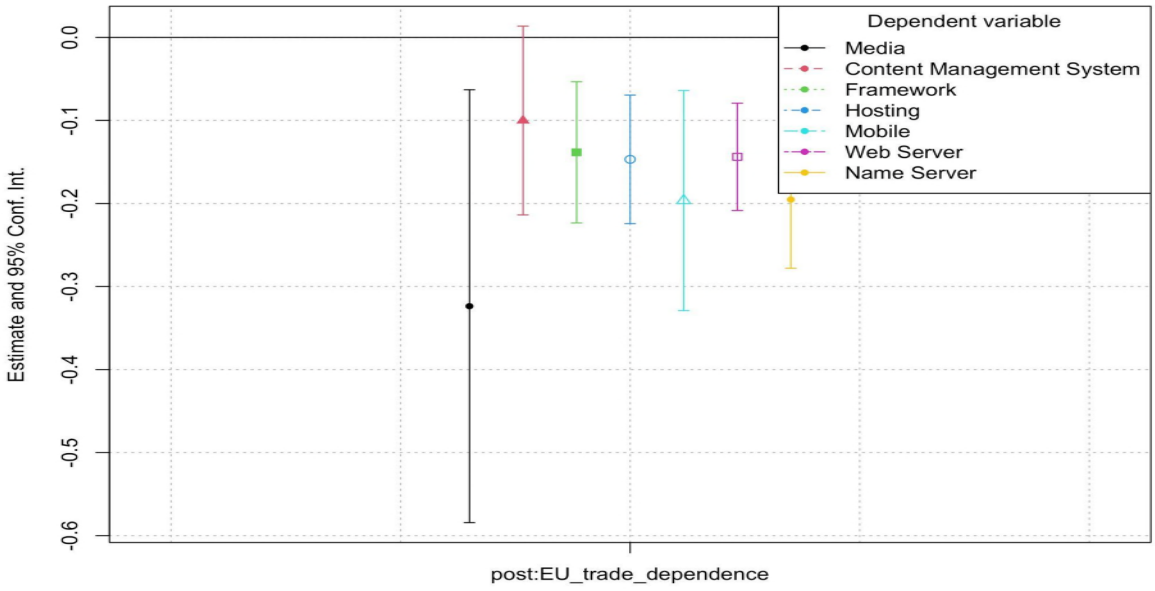
Figure 15: Dynamic treatment effects, 2013-2019



9.8 Coefficient Plot: other technologies

In addition to showing the estimation table, we show the results in a graphic way of a coefficient plot. It clearly shows that for five out of six technologies, the results are statistically significant at the 5% level, with only the content management system being statistically significant at the 10% level. The coefficients vary in size, with the largest coefficient in media, followed by mobile and name server.

Figure 16: Coefficient plot for other technologies



9.9 Brexit as Geographical Surprise Shock

We also run the estimations for Brexit as Geographical Surprise Shock, using the same e-commerce-related technology categories as in the baseline results. We present results in the table below, finding positive effects for all five categories, which are insignificant and small in magnitude. Thus, we conclude that Brexit as Geographical Surprise Shock did not have a substantial impact on the digital technology adoption of SMEs in the UK.

Dependent Variables:	Payment	Secure Layer	Analytics	Javascript	Content Net.	Del.
Model:	(1)	(2)	(3)	(4)	(5)	
Variables						
GSS × post						
	0.009	0.002	0.0010	0.001	0.0003	
	(0.009)	(0.006)	(0.004)	(0.004)	(0.006)	
Fixed-effects						
Firm						
	Yes	Yes	Yes	Yes	Yes	
Year	Yes	Yes	Yes	Yes	Yes	
Region	Yes	Yes	Yes	Yes	Yes	
Fit statistics						
Observations						
	8,778	20,839	15,946	21,406	17,171	
Squared Correlation	0.600	0.441	0.592	0.658	0.632	
Pseudo R^2	0.250	0.219	0.238	0.409	0.330	
BIC	28,165.2	72,681.2	64,090.3	118,511.9	60,500.2	

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*
Clustered (firm) standard-errors in parentheses. Different numbers of observations are explained by the exclusion of firms that never adopt a given technology.

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