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ORIGINAL PAPER

Impacts of Brexit on corporate productivity in the UK: a regionalism perspective

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Abstract
The nexus of Brexit-related uncertainty and corporate productivity in the UK has garnered sufficient attention while a regionalism perspective has also become important given the regional heterogeneity existing in this nexus. This paper documents spatiotemporal growth paths of corporate total factor productivity (TFP) in Wales, a typical UK country, during the period 2013–2019 divided by the 2016 Brexit Referendum. Using firm-level panel data, pooled OLS, fixed effect, and IV analysis, the author demonstrates that corporate TFP growth for firms in Wales was significantly weakened by Brexit-related uncertainty. Firms in South Wales and those with stronger EU-oriented characteristics are more adversely affected by Brexit. The author also conducts mechanism tests and finds that Brexit discourages corporate TFP through channels of establishing additional barriers to trade, FDI inflow, and international inward migration in Wales. PSM-DID analysis is then applied for comparative studies on firms in Wales and Brittany in France, two economically similar regions in Europe, with results similar to benchmark analysis outcomes.

JEL Classification R11 · F53 · D24 · O47

1 Introduction

Total factor productivity (TFP) has been considered as an important measurement that shows the quality of economic growth in a certain economy. Specifically, it gauges productive efficiency by quantifying the amount of output generated per unit of inputs. TFP reflects the allocation of resources, the technological level of production methods, changes in production targets, the level of organisational management in production, the enthusiasm of workers for production and business activities, as well as the degree to which economic systems and various social factors influence production activities (Hulten 2001). As such, it has been widely considered as a

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significant indicator of corporate performance and economic development in numerous countries. In the UK, the private sector forms the main body of the economy and how corporate productivity supports the UK economy has become an extremely important issue not only for policymakers but also for millions of business owners.

Discussions on Brexit have been ongoing for years. One of the major purposes of Brexit is to "take back control of economic sovereignty" and to protect the productivity and competitiveness of firms in the UK (Gamble 2021). However, whether corporate productivity can be "protected" remains a question. It is argued that corporate productivity benefits from technological innovation, open business environments, and free movement of capital and labour (Solvay & Sanglier 1998), while economic or political attempts of isolationism such as Brexit can hardly boost firms' productivity and performance (Roe 2003; Mustafa et al. 2020).

The majority of current literature has focussed on nation-level economic impacts of Brexit in the UK and has not arrived at a regional level, which apparently fails to fulfil the criteria of regionalism given extremely heterogeneous economic growth and business environments in different regions of the UK. The regionalism approach emphasises different impacts of policy shocks (e.g. Brexit) on local economic growth due to economic and business uniqueness of specific regions, and appeal for targeted public policies (Giddens 1985). Wales as a UK country having extremely close economic ties with the EU as well as its own characteristics of economic development requires to be analysed in terms of firm-level productivity affected by Brexit in the within the framework of regionalism. Due to a bulk of existing literature revealing that firms with close economic ties with the EU will more severely suffer from Brexit, analysing how firms in Wales respond to Brexit can provide a critical and pioneering angle for future research on this issue.

This paper aims to unprecedentedly analyse impacts of 2016 Brexit Referendum on corporate TFP in Wales based on firm-level data to provide insight into such impacts in the. It also attempts to examine spatial and corporate heterogeneity for this study and discuss potential mechanisms that contribute to diverse impacts of Brexit-related uncertainty due to the 2016 Referendum on corporate TFP in Wales by adopting a series of empirical methodologies.

It is organised as follows. Section 2 reviews the relevant literature and presents the research hypotheses. Section 3 presents main methods. Section 4 shows the sources and patterns of data. Section 5 presents empirical regression results and results of robustness tests. The final section concludes this paper.

2 Literature review and research hypotheses

2.1 Corporate TFP in the UK and Wales

It has been widely acknowledged that, according to the endogenous growth theory, economic growth primarily stems from internal factors rather than external forces and this theory emphasises that investment in human capital, technological innovation, and knowledge plays a crucial role in fostering economic growth (Aghion et al. 1998). Additionally, the theory highlights positive spillover effects associated

with a knowledge-based economy, ultimately driving economic development. TFP as a major measurement of endogenous growth in this theory acts as a core variable to examine impacts of endogenous drivers such as innovation on economic growth. As such, TFP has been broadly utilised in numerous empirical studies that focus on impacts of external shocks on economic growth in economies such as China, UK, and Japan (Huang et al. 2019; Higon 2007; Maskus & McDaniel 1999).

Modern economic growth theory shows that TFP is the power source for corporate management and development. In recent years, firm-level or corporate TFP has become another popular measurement that demonstrates firm-level growth amid the background of regional economic growth. It refers to the efficiency and productivity of a corporation in generating output relative to its inputs, considering all factors of production such as labour, capital, and technology, and measures the overall effectiveness of a company in utilising its resources to produce goods and services. It also reflects how efficiently a company converts inputs into outputs and is a key indicator of firms' performance and competitiveness in the market (Bournakis & Mallick 2018). Corporate TFP has garnered growing attention among economists since it offers a micro-level foundation of corporate growth to support the judgement of macrolevel economic growth, especially for open economies (Dearden et al. 2000).

The existing literature has listed several components that contribute to corporate TFP (Lagos 2006; Crespo 2008; Demir et al. 2022):

(1) *Labour productivity*. The effectiveness of labour in contributing to output generation in firms is a fundamental component of corporate TFP. It measures how efficiently workers can produce goods or services, often influenced by factors such as skills, training, education, and working conditions.
(2) *Capital efficiency*. The utilisation and efficiency of capital resources (such as machinery, equipment, and buildings) also play a crucial role in determining corporate TFP. Efficient allocation and management of capital assets can lead to higher productivity and output.
(3) *Technological innovation*. With the rapid development of technology such as AI in recent years, integrating cutting-edge technological innovation into production processes can have a profound impact on corporate TFP. By investing in research and development (R&D), adopting new technologies, and refining innovative processes, companies can boost productivity and competitiveness. It is also referred to as innovation spillover effects for firms.
(4) *Improvements in management*. Effective management practices and organisational strategies can influence corporate TFP. Good governance, strategic decision-making, operational efficiency, and resource allocation strategies all contribute to improving overall productivity.
(5) *Quality of outputs*. The quality and suitability of inputs (such as raw materials, components, and supplies) can affect TFP. Using high-quality inputs can usually lead to better output quality and overall productivity.
(6) *External factors*. Economic conditions, public policies, regulatory environment, market competition, and external shocks (such as technological disruptions or

financial crises) can also influence corporate TFP by affecting business operations and investment decisions.

2.2 Policy shock and corporate TFP

2.2.1 Potential mechanisms

Corporate TFP is very likely to have volatility due to policy shocks no matter whether such policy shocks are positive or negative. It is important to theoretically examine how policy shocks, such as Brexit-related extreme changes to economic policies, will impact corporate TFP. Existing literature has focussed on several potential mechanisms through which corporate TFP will face fluctuations due to policy shocks.

First, with regard to trade policies, openness of trade can theoretically allow firms to exploit economies of scale and access cheaper and more diverse inputs, boosting productivity (Krugman 1980), and facilitate technology diffusion and R&D spillovers, driving TFP growth (Romer 1990), according to new trade theory and endogenous growth theory. Empirically, Abizadeh and Pandey (2009) investigate impacts of trade openness on growth of corporate TFP and find that an open trade environment will have overall positive impacts on corporate TFP and the services sector benefits most from trade openness while the agricultural and industrial sectors seem not have received significant effects from such environment. This study presents a valuable reference since trade has played a significant role in the UK economy and output provided by the services sector accounts for over 80% among all sectors in the UK.[1] Dovis and Milgram-Baleix (2009) examine the sensitivity of corporate TFP to trade openness and tariffs in Spain and illustrate that corporate TFP is negatively impacted by European tariffs and other trade barriers since more fierce competition due to increasing foreign products in the domestic market and firm imports will encourage innovation and product upgrades, thus lead to improvements in corporate TFP. Yu (2015) also finds that both import and export tariffs discourage improvements in firm-level productivity in China. In the UK, there is also evidence that shows positive correlations between trade and corporate productivity (Harris & Moffat 2015). Brexit has led to the end of free trade between the UK and EU, causing significant uncertainty of trade, and could harm corporate productivity through the channel of trade (Fingleton et al. 2023; Broadbent et al. 2023). Wales is a region with numerous firms that have frequent trade with the EU market, which results in the first hypothesis:

Hypothesis 1 *Brexit negatively impacts corporate TFP in Wales by undermining free trade between the UK and its counterparts*

[1] See the Research Briefing of Service Industries: https://commonslibrary.parliament.uk/research-briefings/sn02786/.

Second, investment, especially FDI, can have critical impacts on corporate TFP as well. Theoretically, the endogenous growth theory also justifies that FDI brings technology transfers, managerial know-how, and R&D spillovers, boosting corporate productivity. Empirically, Li and Tanna (2019) find that inward FDI and corporate TFP are significantly correlated if the roles of human capital and institutions as contingencies are considered. They also claim that the rapidly growing inward FDI boosted by opening-up policies in developing countries can significantly contribute to corporate productivity growth. Baltabaev (2014) adds that shorter distances to FDI countries of origin with frontier technology will make such impact more remarkable in the FDI inward regions. Turning to the case of the UK, Harris and Moffat (2013) find that FDI contributed to the aggregate TFP in the UK for 1997–2008 and the investment-friendly policy in the UK has led to such growth of TFP. Haskel et al. (2007) focus on impacts of FDI on corporate productivity in the manufacturing sector and suggest a robust and significantly positive correlation between a domestic plant's TFP and the foreign-affiliate share of activity amid an investment-encouraging scheme. Brexit is also expected to bring more barriers to FDI in the UK (McGrattan & Weddle, 2020), thus hinder the growth of corporate TFP, which leads to the second hypothesis:

Hypothesis 2 *Brexit negatively impacts corporate TFP in Wales by discouraging inward FDI*

Third, inward immigration can act as a significant channel through which policy shocks can impact corporate TFP. Immigrants bring skills, education, and training that enhance labour productivity while high-skilled immigrants disproportionately contribute to innovation and TFP growth (Lucas 1988). Empirically, Fassio and Kalantaryan (2020) find that, generally, migrants contribute to the productivity of the sectors in which they are employed with significant heterogeneity across sectors in Europe. Tombe and Zhu (2019) analyse impacts of a representative policy shock, ease of Hukou system in China, on corporate productivity and find that reduction in migration costs causes increase in productivity. Brexit, on the contrary, has imposed additional restrictions on immigration from the EU[2] while EU labour migrants have occupied 72% of all labour migrants in Wales, according to LFS data. Thus, the third hypothesis is:

Hypothesis 3 *Brexit negatively impacts corporate TFP in Wales by unwelcoming inward immigration, especially from the EU*

[2] https://www.epc.eu/content/PDF/2020/11_A_radical_departure.pdf.

2.2.2 Filling the gaps

Brexit as a policy shock has been considered to have caused negative impacts on corporate TFP in the UK. For instance, Reenen and Yang (2023) refer to historical firm-level data of productivity and find that Brexit has led to inferior corporate TFP for firms in the UK compared to firms in France, Germany, and the US. Bloom et al. (2019) find that firm-level productivity was depressed by Brexit due to growing concerns over economic uncertainty related to Brexit, and firms that are more exposed to international trade, owned by EU countries, and belong to sectors that rely heavily on the UK–EU trade are more likely to suffer from corporate TFP decline due to Brexit.

Nevertheless, it is important to note that, to the best of the author's knowledge, relevant studies on the impacts of Brexit on corporate TFP in the UK and its regions with firm-level data are extremely inadequate. It does not mean that discussions on how Brexit affected the aggregate TFP in the UK are scarce, given that multiple studies have revealed that Brexit and its relevant uncertainty of UK–EU trade, FDI to the UK, and broader socioeconomic risks in the UK will bring negative impacts on the UK economy measured by aggregate TFP (McGrattan & Waddle 2020; Broadbent et al. 2023; Fingleton et al. 2023). These discussions have provoked insights into potential mechanisms through which Brexit can affect corporate TFP, i.e. trade, FDI, and immigration.

Although seldomly discussed in the UK, impacts of Brexit on corporate TFP should present spatial and corporate heterogeneity due to multiple reasons including differences in initial levels of local economic growth and firms' own business performance. The heterogeneity issue in the topic of how corporate TFP responds to policy shocks is thoroughly discussed in China. For instance, Liu et al. (2021) reveal that the financialisation project of manufacturing enterprises will have heterogeneous impacts on corporate TFP in China, i.e. firms with initially higher TFP and private ownership will benefit more from the project than other kinds of firms. Zhang and Du (2020) claim that firms in more developed regions and with higher-level green technology will receive more significant effects on corporate TFP from the green development strategy in China. As such, this study will also try to examine the potential heterogeneity of impacts of Brexit on corporate TFP in Wales, which leads to the final hypothesis:

Hypothesis 4 *Spatial and corporate heterogeneity is expected for firms in Wales in terms of impacts of Brexit on corporate TFP*

Although there are a great number of existing studies on Brexit and its impact on corporate TFP, there are still significant research gaps. First, the majority of these studies focus on this issue from a national perspective without highlighting spatial heterogeneity across the UK with a scope of regionalism. Second, few studies have discussed potential mechanisms through which Brexit influenced corporate TFP in the UK. Finally, the Welsh economy and Welsh firms with close economic ties with the EU have been too long ignored, while such analysis is

critical for many other firms sharing strong connections with the EU. This study aims to fill these gaps with advanced methodologies and up-to-date data.

3 Methodology

3.1 Empirical method

This study comprises two empirical methods to provide robust analysis, i.e. the fixed-effect method which only analyses impacts of Brexit-related uncertainty on corporate TFP for firms in Wales, and the PSM-DID method which tries to provide comparative analysis on corporate TFP for firms in Wales by comparing it with corporate productivity for firms in Brittany, a French region which shares extremely similar macroeconomic and industrial patterns with Wales. Reasons for choosing firms in Brittany as the control group include:

(1) Spatial economic similarity: Both Wales and Brittany are located in peripheral areas of their perspective countries and share strong economic connections with other EU countries, and such connections are even stronger for Brittany since France itself is an EU member (Reddé, 2022).
(2) Local economic growth: Wales and Brittany have similar scales of economic growth measured by GDP per capita (£27,274 for Wales and €33,648 for Brittany[3]), similar industrial structures with focus on agricultural and manufacturing industries, and similar small capitals serving as local economic hubs (Le Berre 2021; Henry 2020).
(3) Similar trade patterns: Other EU countries are dominant trade partners of both Wales and Brittany and during the sample period (2013–2019), both of them belong to EU free trade area.
(4) Cultural and institutional similarities: Both Wales and Brittany have their own regional languages and local identities, and both of them are governed under decentralised regional governments (Siloret 2015).

First, with regard to the fixed-effect analysis, the author establishes the following empirical model:

$$\mathrm{CTFP}_{\mathrm{it}} = \alpha_0 + \alpha_1\left(U_{\mathrm{it}} \times \mathrm{Post}_t\right) + \gamma X_{\mathrm{it}} + f_i + m_t + \varepsilon_{\mathrm{it}} \quad (1)$$

where $\mathrm{CTFP}_{\mathrm{it}}$ stands for the corporate TFP for firm i in year t; the coefficient α_1 measures the impacts of Brexit on corporate TFP for firms in Wales; U_{it} represents the extent of Brexit exposure for each firm in Wales, measured by the Brexit Uncertainty Index; Post_t is a Brexit dummy variable which equals to 1 if t is larger than 2016 since the Brexit Referendum is considered to have brought significant economic uncertainty to firms in the UK; $U_{it} \times \mathrm{Post}_t$ is the core independent variable

[3] https://www.insee.fr/fr/statistiques/serie/010751771.

in the form of an interaction term that denotes how and when each firm in Wales was impacted by Brexit; X_{it} is a set of firm-level control variables; f_i and m_t are firm and year fixed-effect terms; ε_{it} is the random error term. It is important to highlight that in this DID model, the local-council or city control variable is not included due to lack of local-council-level macroeconomic data in Wales. Although it is possible that economic growths among different local councils in Wales might vary, the author believes that the set of firm-level control variables can eliminate sample selection bias and other potential statistical bias as much as possible due to the large amount of samples and adequate variables that measure firms' business performance.

Second, this study also includes PSM-DID analysis by comparing corporate productivity of firms in Wales and Brittany to provide another empirical evidence and make results of this study more robust. The PSM-DID model is as follows:

$$\mathrm{CTFP}_{it} = \beta_0 + \beta_1 \left(\mathrm{Treat}_i \times \mathrm{Post}_t\right) + \gamma X_{it} + f_i + m_t + \varepsilon_{it} \tag{2}$$

where CTFP_{it}, X_{it}, f_i, m_t, and ε_{it} denote the same meanings as in Eq. (1). The current interaction term, $\mathrm{Treat}_i \times \mathrm{Post}_t$, represents whether the firm i was directly impacted by Brexit in year t, where Treat_i will equal to 1 if this firm is located in Wales and 0 if this firm is in Brittany, and Post_t will equal to 1 if t is larger than 2016. Thus, the coefficient of this interaction term reflects the impact brought by Brexit Referendum directly by comparing corporate TFP for firms in Wales and Brittany, i.e. between the UK and France. The author uses the PSM-DID method since the use of the DID method requires a crucial precondition that the treatment group and the control group exhibit a common trend (Rosenbaum & Rubin 1983). This means that without the policy shock of Brexit, there should be no systematic difference in the overall change trend of listed companies in Wales and Brittany over time. However, in reality, significant regional disparities still exist if all socioeconomic factors are considered in these two regions, rendering this assumption often inadequate. Thus, this study employs the more advantageous PSM-DID method to account for unobservable differences that do not vary over time between groups, thereby deriving impacts of policy shock of Brexit (See Appendix for detailed illustrations of PSM practice).

3.2 Variables

3.2.1 Dependent variable

The dependent variable of this study is corporate TFP. There are three primary approaches used in academic research to calculate total factor productivity (TFP). The initial approach falls under the parameter method, exemplified by Solow's residual method and stochastic frontier analysis (Fuentes & Morales 2011). However, the stochastic frontier function's functional form and distribution assumptions are often too stringent for practical application. The second type encompasses nonparametric methods like the data envelope analysis (Danquah et al. 2014; Zhu et al. 2018), which relies entirely on data-driven techniques.

The final approach is the semiparametric method, typified by the Levinsohn–Petrin (LP) methods (Levinsohn & Petrin 2003). This method involves first estimating the coefficients of independent variables to discern the influence of state variables on intermediate inputs versus outputs. Subsequently, this method estimates the coefficients of state variables and independent variables and can effectively address endogeneity and sample selection bias issues arising from the correlation of TFP within residual input factors. Thus, this study adopts the LP method to proceed with empirical analysis.

The essential idea of the LP method is to utilise the intermediate input of a firm as a proxy variable for corporate TFP. It assumes that the firm makes business decisions based on current productivity of this firm. Equation (3) shows the typical relationship between enterprise input and output, where y_{it} represents corporate output; W_{it} represents the free variable measured by payroll reflecting the cost of labour; X_{it} is a state variable often measured by enterprise capital; ω_{it} denotes the corporate TFP; ε_{it} is the white noise.

$$y_{it} = \alpha + \beta W_{it} + \gamma X_{it} + \omega_{it} + \varepsilon_{it} \tag{3}$$

According to Levinsohn and Petrin (2003), corporate TFP can thus be estimated by Eq. (4). LP method assumes that corporate TFP conforms to the first-order Markov process, where $\Omega_{i,t-1}$ means the decision information set and ξ_{it} is productivity shock which is irrelevant to corporate TFP and state variables.

$$\omega_{it} = E\left(\omega_{it}|\Omega_{i,t-1}\right) + \xi_{it} = E\left(\omega_{it}|\omega_{i,t-1}\right) + \xi_{it} \tag{4}$$

LP method also assumes that the intermediate input M_{it} depends on X_{it} and ω_{it} while M_{it} will increase monotonously with X_{it} and ω_{it}. Equation (6) can be derived from Eq. (5).

$$M_{it} = f\left(X_{it}, \omega_{it}\right) \tag{5}$$

$$\omega_{it} = f^{-1}\left(M_{it}, X_{it}\right) = h\left(M_{it}, X_{it}\right) \tag{6}$$

Then, insert Eq. (6) into Eq. (3) to get Eq. (7), where $\varphi_{it}\left(M_{it}, X_{it}\right)$ is equal to $\gamma X_{it} + h\left(M_{it}, X_{it}\right)$.

$$y_{it} = \alpha + \beta W_{it} + \varphi_{it}\left(M_{it}, X_{it}\right) + \varepsilon_{it} \tag{7}$$

As is shown in Eq. (7), a third-order polynomial containing the M_{it} and X_{it} is replaced by the term $\varphi_{it}\left(M_{it}, X_{it}\right)$. Thus, Eq. (7) can be estimated by OLS to obtain estimated coefficient $\hat{\beta}$ of W_{it}, so that Eq. (8) can be derived, where $\eta_{it} = \xi_{it} + \varepsilon_{it}$.

$$\begin{aligned} y_{it} - \hat{\beta} W_{it} &= \alpha_0 + \gamma X_{it} + \omega_{it} + \varepsilon_{it} \\ &= \alpha_0 + \gamma X_{it} + E\left(\omega_{it}|\omega_{i,t-1}\right) + \xi_{it} + \varepsilon_{it} \\ &= \alpha_0 + \gamma X_{it} + E\left(\omega_{it}|\omega_{i,t-1}\right) + \eta_{it} \end{aligned} \tag{8}$$

Construct $\hat{\omega}_{\mathrm{it}} = \delta_0 + \delta_1\omega_{i,t-1} + \delta_2\omega_{i,t-1}^2 + \delta_3\omega_{i,t-1}^3 + \theta_{\mathrm{it}}$ to calculate the nonparametric consistency estimate of expected value $\hat{E}\left[\omega_{\mathrm{it}}|\omega_{i,t-1}\right]$. Since we have known $\widehat{\omega_{\mathrm{it}}} = \widehat{\varphi_{\mathrm{it}}} - \gamma X_{\mathrm{it}}$ and $\hat{\omega}_{i,t-1} = \hat{E}\left[\omega_{\mathrm{it}}|\omega_{i,t-1}\right] + \xi_{\mathrm{it}}$, these two equations can be inserted into Eq. (8) and we can get Eq. (9).

$$y_{\mathrm{it}} - \hat{\beta}W_{\mathrm{it}} = \alpha_0 + \gamma X_{\mathrm{it}} + \hat{E}\left[\omega_{\mathrm{it}}|\omega_{i,t-1}\right] + \xi_{\mathrm{it}} + \varepsilon_{\mathrm{it}} \tag{9}$$

Thus, the residual $\eta_{it} = \xi_{it} + \varepsilon_{it}$ can be obtained from Eq. (9), which is corporate TFP:

$$\eta_{\mathrm{it}} = y_{\mathrm{it}} - \hat{\beta}W_{\mathrm{it}} - \alpha_0 - \gamma X_{\mathrm{it}} - \hat{E}\left[\omega_{\mathrm{it}}|\omega_{i,t-1}\right] \tag{10}$$

Additionally, it is important to note that the LP method leads to revenue TFP with potential markup. However, existing studies on impacts of Brexit on corporate TFP in the UK, such as Bloom et al. (2019), have revealed that markup is not the channel through which Brexit imposed impacts on corporate TFP, since trends of markup are found to be identical for firms in the UK and other countries, at least before 2020. Thus, it is safe to apply LP method in this study with markup controlled. Meanwhile, the author adopts Ackerberg–Caves–Frazer (ACF) approach (Ackerberg et al., 2015) to address potential non-monotonicity in input choices post-Brexit. The results remained consistent with our initial estimates, suggesting that Brexit-related bias on intermediate factors is minimal.

3.2.2 Independent variable

For the fixed-effect analysis, the independent variable is $U_{\mathrm{it}} \times \mathrm{Post}_t$ in the form of an interaction term that denotes how and when each firm in Wales was impacted by Brexit-related uncertainty. U_{it} comes from the Brexit Uncertainty Index (BUI) which combines the BUI data released by Bank of England in 2016–2019 (Bloom et al. 2019) and the BUI data released by Chun et al. (2023) from the University of Birmingham in 2013–2019. The BUI by Chun et al. (2023) consists of multiple novel news-based indicators of Brexit uncertainty at both aggregate and topic-specific level for the UK economy and business environment based on textual analysis and machine learning methods. They also include data analysis on key words of Brexit and business uncertainty in news, business reports, corporate annual reports, and social media in the UK to estimate how business owners responded to Brexit and relevant concerns. More specifically, following Chun et al. (2023) and Bloom et al. (2019), U_{it} shows firm-specific exposure to Brexit-related uncertainty through the following equation:

$$U_{\mathrm{it}} = \alpha_o + \beta_1\mathrm{Brexit}_{\mathrm{it}} + \beta_2\mathrm{EUT}_{\mathrm{it}} + \beta_3\mathrm{EUI}_{\mathrm{it}} \tag{11}$$

where $\mathrm{Brexit}_{\mathrm{it}}$ represents logarithmic frequency of the word "Brexit" on all reports released by each sample firm in each year, and this textual analysis uses machine learning and natural language processing (NLP) techniques to count the frequency of Brexit-related terms; $\mathrm{EUT}_{\mathrm{it}}$ means the proportion of EU-related trade in total trade volumes of the specific firm in a year; $\mathrm{EUI}_{\mathrm{it}}$ means the proportion of EU-related

investment in the specific firm in a year. After reviewing empirical results from Chun et al. (2023) and Bloom et al. (2019) and calibration, values of α_0, β_1, β_2, β_3 are 0.3, 0.5, 0.3, and 0.2, respectively. For the PSM-DID analysis, the independent variable is the Brexit dummy which presents in the form of $\text{Treat}_i \times \text{Post}_t$ representing whether the firm i was directly impacted by Brexit in year t, where Treat_i will equal to 1 if this firm is located in Wales and 0 if this firm is in Brittany, and Post_t will equal to 1 if t is larger than 2016.

3.2.3 Moderating variables

As is discussed in previous sections, numerous scholars have found that Brexit-related uncertainty might have caused significant effects on FDI inflow to the UK, international migration to the UK, and international trade for the UK with its trade partners, especially EU countries. Meanwhile, whether these channels have moderating effects on corporate TFP for individual firms in Wales depends on whether firms are vulnerable to Brexit. Hence, this study incorporates EU-related FDI inflow, inward migration, and trade into the benchmark model and establishes a set of equations that perform the mechanism tests.

3.2.4 Control variables

Economic development status and local economic growth might significantly impact corporate productivity in a certain region (Ding et al. 2016). Meanwhile, initial business performance and endowments might affect the development of corporate TFP for firms as well (Duguet, 2006). Therefore, this study uses several control variables that belong to both macrolevel and corporate level: (1) on the macrolevel, they include GDP per capita, unemployment rates, inflation rates, FDI inflow, and total trade volumes in Wales; (2) on the corporate level, they include total revenue, return-on-asset, net profit margin, number of employees, capital-output ratio, current ratio represented by the debt-to-asset ratio, and the length of business operation.

3.2.5 Research area

The research area of this study covers all 22 local authorities in Wales since each local authority has at least one sample firm according to the database utilised for this study (See Fig. 1). It is found that firms in South Wales are significantly more than those in other parts of Wales.

4 Data

Data of essential variables to calculate corporate TFP for firms in Wales come from the FAME database. It is a comprehensive source of firm-level financial and business information for thousands of firms in the UK and Ireland. This database provides a series of corporate data including:

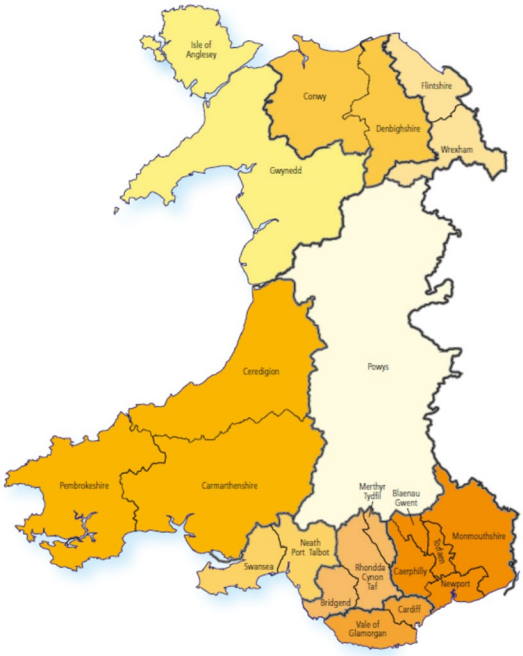

Fig. 1 Map of Wales on local authority level. *Notes*: This map displays current 22 local authorities in Wales. Wales can be divided into four areas, i.e. North Wales consisting of 6 local councils, Mid Wales consisting of 2 local authorities, Southwest Wales consisting of 4 local councils, and Southeast Wales consisting of 10 local authorities. Source: The Welsh Government

(1) *Company information*: Detailed profiles of companies including financials, ownership structures, industry classifications, and contact details.
(2) *Financial statements*: Access to balance sheets, income statements, cash flow statements, and other financial metrics for companies.
(3) *Company performance metrics*: Analysis tools and metrics to assess company performance and financial health.
(4) *Ownership Information*: Details on company ownership, subsidiaries, and group structures.
(5) *Market Data*: Information on market trends, industry analysis, and sector performance.
(6) FAME database has been utilised by multiple empirical studies on firm-level productivity and corporate performance. For instance, Hutchinson et al. (2022) use the FAME data to analyse impacts of private hedge fund on corporate incentives and performance. Lavery et al. (2024) focus on impacts of private equity buyouts on export activity for firms in the UK during the Brexit period, 2012–2019, using the FAME dataset. Removing firms with missing data or discontinued operation, the author compiled a panel consisting of 123,372 sample firms spanning the period from 2013 to 2019.

Regarding corporate productivity in the UK, Fig. 2 shows the historical trend of UK's corporate TFP from 2008 to 2019. It can be found that the revenue weighted corporate TFP for firms in the manufacturing industry decreased from 1.1 in 2008 to 0.8 in 2019, showing the declining general trend of corporate productivity for the

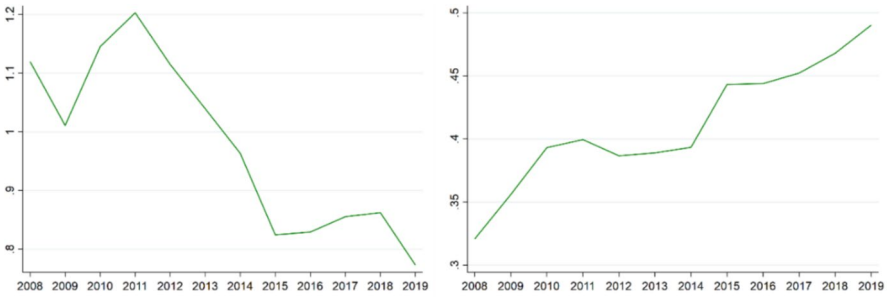

Fig. 2 Corporate TFP trends in the UK. *Notes*: The left figure shows the revenue weighted corporate TFP for manufacturing industry, and the right figure shows the revenue weighted corporate TFP for other industries. Sources: The Office for National Statistics (ONS) Annual Business Survey and estimates provided by Coyle et al. (2023)

manufacturing industry in the UK. It is consistent with several studies, such as Godley (2023) who claims that the manufacturing output in the UK has increased significantly less than the output of other goods and services. Harris and Moffat (2019) take a more relevant approach to analyse the manufacturing growth in the UK from 1973 to 2012 using firm-level TFP and demonstrate the decline of this industry in past decade.

The regionalism approach highlights heterogeneous economic growth, industrial structure, and business environments in different regions inside a country, thus the Welsh economy as a significant component of the UK economy deserves more academic attention. Figure 3 illustrates the trend of log linearised corporate TFP for firms in Wales, showing that the log linearised corporate TFP increased from 0.2 in

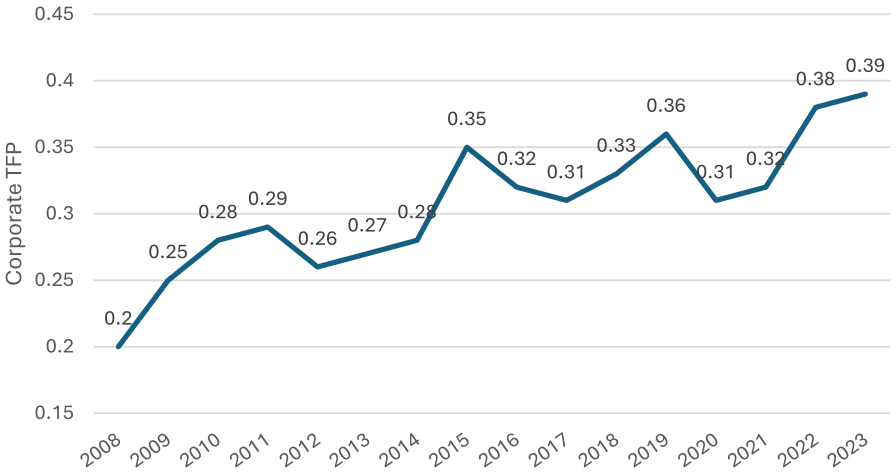

Fig. 3 Corporate TFP trends in Wales, logged. Notes: Data source includes firm-level Bureau Van Dijk FAME database, the ONS Annual Business Survey data related to firms in Wales, and the ONS Labour Force Survey data related to firms in Wales. Final results of corporate TFP estimates in Wales come from the author's calculation

2008 to 0.39 in 2023 and presents a generally steady rise in the past 15 years. It is also crucial to highlight two specific periods, i.e. 2016–2018 and 2020–2021, when corporate TFP in Wales experienced significant decline, potentially due to the 2016 Brexit Referendum and the Covid-19 pandemic, respectively.

For the comparative study on firms in Wales and Brittany based on PSM-DID analysis, the author uses one of the most comprehensive firm-level data sources in France, the SIRENE database, to extract firm-level data of the same variables during the same period. SIRENE is the official database of corporate performance provided by the French National Institute of Statistics and Economic Studies (INSEE) and includes thousands of corporate records such as company information, financial status, market performance, and operational structures.[4] The same 123,372 sample firms in Brittany from 2013 to 2019 are extracted to match the sample size of firms in Wales. It is also important to note that during the process of matching firm-level data in these two regions, the sampling procedure is totally random so that sample bias can be reduced to minimum.

Data for corporate level control variables also come from FAME and SIRENE databases. Data for regional control variables in Wales rely on the ONS annual data of multiple variables that measure economic growth in Wales and Welsh Government Statistics that include annual reports of the Welsh economy. Data for regional control variables in Brittany rely on the section of regional economic statistics (statistiques régionales) from National Institute of Statistics and Economic Studies (INSEE) in France, annual economic reports provided by Regional Chamber of Commerce and Industry (CCI) of Brittany, and regular statistics of local economic growth released by Bank of France (Banque de France).

5 Results and discussions

5.1 Descriptive statistics

The descriptive statistics of all variables for the benchmark model are summarised in Table 1, and non-percentage continuous variables are taken in the logarithmic form.

Brexit Uncertainty Index has the range from 0 (minimum) to 100% (maximum), and data of BUI show that firms in Wales universally have relatively high-level concerns over business uncertainty due to Brexit. For macroeconomic control variables, all of them show little fluctuation during the sample period. For firm-level control variables, it can be found that data of several variables such as the number of employees, length of operation, and net profit margin vary significantly among sample firms.

[4] See the official website of SIRENE (in French): https://www.data.gouv.fr/fr/datasets/base-sirene-des-entreprises-et-de-leurs-etablissements-siren-siret/.

Table 1 Summary statistics and operationalisations

Variables	Mean	S.D	Min	Max	Operationalisation
lnCTFP	0.383	1.219	0.151	0.675	Corporate TFP, logged
U_i	0.593	0.204	0.513	0.652	Brexit Uncertainty Index
$Post_t$	0.521	0.034	0	1	Brexit identification term
Macroeconomic control variables					
lnGDP	4.285	0.078	3.971	4.586	GDP per capita in Wales, logged
UR	0.072	0.023	0.031	0.095	Annual average unemployment rate in Wales
IR	0.062	0.046	0.048	0.074	Annual average inflation rate in Wales
lnFDI	7.289	0.108	6.628	7.856	FDI values in Wales, logged
lnTrade	8.003	0.098	7.745	8.329	Total trade volumes, logged
Firm-level control variables					
lnRevenue	5.457	1.663	3.232	8.433	Total revenue, logged
ROA	0.673	1.554	0.231	1.114	Return-on-Asset ratio
NPM	0.328	2.205	0.123	0.506	Net profit margin ratio
lnN	2.655	2.567	1.033	4.478	Number of total employees, logged
COR	0.852	1.456	0.571	1.138	Capital-Output ratio
DAR	0.762	1.562	0.486	0.997	Debt-to-Asset ratio
lnLife	1.206	3.378	0.482	2.079	Number of years of operation, logged
IV-related variables					
SaleEU	0.671	1.744	0.333	0.927	Share of sales to the EU
EULabour	0.127	1.323	0.076	0.198	Share of EU migrants in the firm
EUOwner	0.012	3.672	0	1	EU ownership dummy (1 = owned by EU countries, 0 otherwise)

1. The data for share of sales to the EU, share of EU migrants among all employees, and EU ownership comes from the FAME database and the Labour Force Survey (LFS) database. 2. Three EU-related variables are for the IV estimation

5.2 Baseline analysis

The results of the baseline regression of the DID model are presented in Table 2. As is shown in this table, columns (1)–(5) represent results of two OLS analysis, two FE analysis, and IV estimation based on the benchmark model. Specifically, column (1) shows results of basic OLS without control variables. As the error term might contain control variables that influence the corporate TFP, column (2) introduces control variables on both macroeconomic and corporate levels on the basis of column (1). The regression results are then obtained by controlling for year FE as shown in column (3) and controlling for year, firm, and region (macroeconomic growth) FE as shown in column (4). Column (5) illustrates results of IV estimation by adding three EU-related instrumental variables to examine whether firms with closer economic ties with the EU suffered more corporate TFP loss from Brexit.

Results indicate that: (1) Brexit uncertainty after the 2016 Referendum is significantly and negatively correlated with corporate TFP for firms in Wales under all regression circumstances; (2) during the sample period (2013–2019), growth in

Table 2 Baseline regression results

Dependent variable	TFP: OLS1 (1)	TFP: OLS2 (2)	TFP: FE1 (3)	TFP: FE2 (4)	TFP: IV (5)
$U_i \times Post_t$	−0.247***		−0.204***		
	(0.345)		(0.994)		
lnGDP		0.543***		0.423***	0.327**
		(−3.329)		(5.742)	(2.339)
UR		−0.034		−0.037	−0.021
		(0.456)		(2.726)	(0.997)
IR		0.021		0.035	0.038
		(1.477)		(1.287)	(0.305)
lnFDI		0.108***		0.102***	0.112***
		(2.034)		(3.338)	(0.027)
lnTrade		0.127***		0.104***	0.118***
		(1.002)		(2.089)	(0.977)
lnRevenue		0.562**		0.533**	0.572**
		(−1.378)		(1.776)	(2.544)
ROA		0.327**		0.301**	0.311**
		(1.303)		(4.467)	(2.646)
NPM		0.018**		0.015**	0.016**
		(0.412)		(1.003)	(0.564)
lnN		0.125		0.103	0.127
		(5.892)		(0.789)	(1.346)
COR		0.036**		0.033**	0.030**
		(1.873)		(0.912)	(1.435)
DAR		−0.005**		−0.004**	−0.007**
		(4.198)		(2.659)	(−1.728)
lnLife		0.028**		0.021**	0.017**
		(3.902)		(4.698)	(0.345)
Constant	1.205***	0.467***	1.023***	0.683***	0.902***
	(5.673)	(−2.689)	(4.238)	(−1.127)	(0.835)
Year FE	No	No	Yes	Yes	Yes
Firm FE	No	No	No	Yes	Yes
Region FE	No	No	No	Yes	Yes
Observations	986,976	986,976	986,976	986,976	986,976
R-squared	0.034	0.532	0.367	0.602	0.568

***, **, and * indicate the 1%, 5%, and 10% significance levels, respectively

GDP per capita, FDI inflow, and trade seem to have significant impacts on improving corporate TFP and reducing negative impacts of the Brexit shock on corporate performance in Wales; (3) firms with higher revenue, return-on-asset, net profit margin, capital-output ratio, and lower debt-asset ratio, and longer life of operation seems to have higher corporate TFP than other firms; (4) IV analysis shows that

for firms with higher proportions of sales to the EU, more EU labour migrants, and EU ownership, corporate TFP will be more significantly discouraged by Brexit. The firm-level heterogeneity of EU-related variables will be further analysed in the next section.

Results above are highly consistent with existing literature in the following aspects: (1) the 2016 Referendum and its outcome have caused significant concerns over uncertainty of the economic and business environment in the UK and corporate productivity was negatively impacted by Brexit since firms tended to reduce or postpone investment, reduce recruitment, and transfer capacity of production to de-risk from Brexit (Hill et al. 2019), which seems to also have happened in Wales; (2) macroeconomic data show that the Welsh economy remains relatively strong since the 2010s, especially that GDP per capita, international trade, and FDI inflow steadily increased, which acts as a counteracting effect that smoothened the shock of Brexit; (3) the theory of economies of scale highlights the cost and productivity advantages that firms can achieve as their scale of production increases (Stigler 1958) and this study provides empirical evidence to support this theory; (4) multiple studies have revealed that firms with close economic contact with EU countries or EU ownership in the UK might be impacted more severely by Brexit as discussed above, and our empirical results based on the benchmark model provide another evidence by using the case of firms in Wales.

In addition, the IV analysis is included to examine heterogeneous impacts of Brexit on firms with frequent or infrequent business connections with EU countries with three EU-related variables, i.e. share of sales to the EU, share of EU labour migrants in the firm, and EU ownership dummy. Existing studies have revealed that trade with the EU (Kren & Lawless 2024), EU labour migrants (Sargent 2023), and EU ownership of firms (Barron & Boutary 2021) represent the closeness of the UK-EU economic interactions, which significantly dominates the magnitude of Brexit-related uncertainty, since the majority of economic and trade barriers due to Brexit are implemented specifically for UK-EU commercial relations, while no evidence is found that closer economic ties with the EU can directly lead to higher productivity. In fact, existing literature (Rafique et al. 2025; Xu et al. 2022) also finds that trade, labour migrants, and firm ownership associated with shock-relevant groups can be used as IVs to analyse impacts of policy shock on corporate productivity. Application of IV analysis can also omit the issue of potential endogeneity, i.e. firms' own features might affect corporate TFP. After applying the Staiger & Stock (1994) rule of thumb, the author finds that F-statistics for all three IVs are over 10, indicating that these IVs are feasible for this study. Results of IV analysis are shown in Table 3.

6 Comparative PSM-DID analysis (See Appendix)

6.1 Heterogeneity analysis

Considering remarkable gaps in economic growth and business development among different regions in Wales, the author first conducts the spatial heterogeneity

Table 3 IV regression results

	(1)	(2)	(3)
SaleEU	0.201**		
	(0.023)		
EULabour		0.346**	
		(1.766)	
EUOwner			0.156**
			(0.048)
Constant	2.306***	2.728***	1.981***
	(0.043)	(5.589)	(0.587)
Staiger and Stock F-Statistics	10.28***	12.27***	11.35***
Sargan J-Statistic (*P*-value)	0.671	0.583	0.779
Year FE	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Observations	986,976	986,976	986,976
R-squared	−0.784	0.308	0.337

***, **, and * indicate the 1%, 5%, and 10% significance levels, respectively

analysis. Columns (1) to (4) of Table 4 report the results of the spatial heterogeneity test, which confirm the existence of significant regionally heterogeneous effects of Brexit-related uncertainty on corporate TFP.

Results of spatial heterogeneity test show that firms in Southwest and Southeast Wales receive more significant impacts of Brexit-related uncertainty on corporate TFP than other regions of Wales, potentially due to these two regions having relatively higher-level economic development and business environment with close economic connections with the EU region. The coefficient for firms in Southeast Wales

Table 4 Spatial heterogeneity test results

Variable	North Wales (1)	Mid Wales (2)	S.W. Wales (3)	S.E. Wales (4)
$U_i \times Post_t$	−0.135*	−0.167	−0.205**	−0.221***
	(1.736)	(3.729)	(2.343)	(0.477)
Constant	0.789*	1.347	1.018**	1.219***
	(1.328)	(3.104)	(0.089)	(1.248)
Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Observations	185,438	106,782	263,693	431,063
R-squared	0.208	0.437	0.689	0.546

***, **, and * indicate the 1%, 5%, and 10% significance levels, respectively. Coefficients of firm and region control variables are emitted

is the most significant, consistent with several studies showing that this region, especially the Cardiff Capital Region and its contiguous local authorities, provides the majority of economic growth and productivity in Wales and owns numerous firms that have frequent trade, labour, and capital exchange and cooperation with the EU region (Alden & Essex 2014). Knight et al. (2017) and Mallet-Garcia et al. (2022) also find that this region is one of the most important migration destinations for EU migrants in the UK and the proportion of EU labour for firms in this region is notably high, which offers another potential reason for significant impacts of the Brexit Referendum shock on corporate TFP.

In addition, following Chadha and Berrill (2021), the author constructs the firm heterogeneity test to examine whether firms with closer economic ties with the EU will be more significantly impacted by Brexit Referendum with regard to corporate TFP. Columns (1) to (3) of Table 5 reveal the results of heterogeneity test for firms with sales to the EU occupying at least 50% in the total sales volume, with EU labour occupying at least 50% in total non-UK employees, and with EU ownership, respectively. As we can see in this table, coefficients for firms in all categories are significant and the absolute values of these coefficients are extremely larger than coefficients in Table 2, indicating that firms with high proportions of sales to the EU or EU labour or owned by EU countries experience more remarkable decline in corporate TFP due to Brexit Referendum.

These findings also echo the existing literature in the following aspects: (1) Brexit agreements include additional restrictions and barriers to the UK-EU trade, such as additional customs checks, tariffs on goods and services, and regulatory divergence, which might have negative impacts on EU-oriented firms in the UK (Buigut & Kapar 2023); (2) EU labour migrants now have to apply for workers' visas and losing the right of free movement might reduce the number of EU migrants to the UK, thus discouraging firms in the UK from obtaining labour resources and innovation brought by EU migrants (Simionescu et al. 2017); (3) firms with EU ownership in the UK will experience reluctance of investment and business expansion, supply

Table 5 Firm heterogeneity test results

Variable	Sales to EU	EU labour	EU owned
	(1)	(2)	(3)
$U_i \times Post_t$	−0.479***	−0.893***	−0.683***
	(6.215)	(3.336)	(0.846)
Constant	0.209***	0.367***	0.284***
	(0.263)	(3.101)	(1.261)
Year FE	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Observations	83,604	53,099	34,995
R-squared	0.403	0.496	0.365

***, **, and * indicate the 1%, 5%, and 10% significance levels, respectively. Coefficients of firm and region control variables are emitted

chain disruptions, market volatility, and more trade barriers due to Brexit, thus corporate TFP of these firms might face higher risks (Lin & Chen 2020).

6.2 Mechanism tests

Three potential mechanisms through which Brexit-related uncertainty impacts corporate TFP have been established, i.e. EU-related trade, FDI inflow, and inward migration. Thus, the following equations are constructed to conduct the mechanism tests. Specifically, these equations include three interaction terms $\text{Brexit}_{\text{it}} \times \text{Trade}_{\text{it}}$, $Brexit_{it} \times FDI_{it}$, and $Brexit_{it} \times M_{it}$ that examine the effectiveness of these potential mechanisms in correlations between Brexit and corporate TFP in Wales. Here, $\text{Brexit}_{\text{it}}$ represents the core independent variable indicating the extent of being impacted by Brexit. More specifically, for instance, Eq. (11) is constructed by taking the Brexit uncertainty indicator and total trade volumes/FDI/immigration as explanatory variables and corporate TFP as the explained variable. Equation (12) then adds the multiplicative term of Brexit uncertainty indicator and trade/FDI/immigration as an explanatory variable to Eq. (11). Thus, if the coefficient ρ_3 is significant, trade/FDI/immigration can be considered as moderating channels of Brexit on corporate TFP. The very same logic is applied to other two mechanism tests.

$$\text{CTFP}_{\text{it}} = \alpha_0 + \alpha_1 \text{Brexit}_{\text{it}} + \alpha_2 \left\{ \text{Trade}_{\text{it}}, \text{FDI}_{\text{it}}, M_{\text{it}} \right\} + \gamma X_{\text{it}} + f_i + m_t + \varepsilon_{\text{it}} \quad (12)$$

$$\text{CTFP}_{\text{it}} = \rho_0 + \rho_1 \text{Brexit}_{\text{it}} + \rho_2 \left\{ \text{Trade}_{\text{it}}, FDI_{it}, M_{it} \right\} + \rho_3 \text{Brexit}_{\text{it}} \times \left\{ \text{Trade}_{\text{it}}, \text{FDI}_{\text{it}}, M_{\text{it}} \right\} + \gamma X_{\text{it}} + f_i + m_t + \varepsilon_{\text{it}} \quad (13)$$

Columns (1) to (6) in Table 6 show the regression results for the moderating effects of EU-related trade, FDI inflow, and inward international migration for impacts of Brexit on corporate TFP for firms in Wales. Coefficients of the Brexit indicator and three interaction terms are all significant at the 10% level. Results show that EU-related trade, FDI inflow, and international inward migration in Wales act as mechanisms through which Brexit imposed significant impacts on corporate TFP for firms in Wales. Specifically, since the absolute values of coefficients of all interaction terms are larger than those of the Brexit indicator only, trade, FDI inflow, and inward migration can be considered to strengthen negative impacts of Brexit on corporate TFP due to negative effects of Brexit on trade, FDI inflow, and inward migration especially from the EU region.

6.3 Robustness tests

Table 7 presents the results of a series of robustness tests, including changing the calculation method of corporate TFP, moving outliers, and changing the sample period. First, corporate TFP is now calculated as the residual from the following production function in the form of Eq. (17) developed by Gordon (2017), which was initially used in the US.

Table 6 Mechanism test results

Variable	Trade only	Brexit-Trade	FDI only	Brexit-FDI	Migration only	Brexit-Migration
	(1)	(2)	(3)	(4)	(5)	(6)
$U_i \times Post_t$	−0.038**	−0.077**	−0.284***	−0.227***	−0.015***	−0.028***
	(4.239)	(2.189)	(2.796)	(3.823)	(3.067)	(0.144)
$Trade_{it}$	0.029**	0.023**				
	(−0.978)	(−0.002)				
$Brexit_{it} \times Trade_{it}$		−0.295**				
		(2.366)				
FDI_{it}			0.036**	0.033**		
			(2.053)	(3.685)		
$Brexit_{it} \times FDI_{it}$				−0.037*		
				(−0.978)		
M_{it}					0.027**	0.023**
					(3.516)	(1.154)
$Brexit_{it} \times M_{it}$						−0.111***
						(−1.123)
Constant	1.692**	1.248**	1.277***	1.037***	1.145***	1.095***
	(2.659)	(−0.914)	(−1.313)	(2.062)	(1.653)	(−2.714)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	986.976	986.976	986.976	986.976	986.976	986.976
R-squared	0.345	0.377	0.498	0.505	0.589	0.300

***, **, and * indicate the 1%, 5%, and 10% significance levels, respectively. Coefficients of firm and region control variables are emitted

Table 7 Robustness test results

Variable	CTFP calculation	Outliers	Period change
	(1)	(2)	(3)
$U_i \times Post_t$	−0.233***	−0.426***	−0.501***
	(3.508)	(4.152)	(0.494)
Constant	0.105***	0.127***	0.123***
	(−5.803)	(1.653)	(1.582)
Year FE	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Observations	986,976	725,558	758,901
R-squared	0.345	0.367	0.303

***, **, and * indicate the 1%, 5%, and 10% significance levels, respectively. Coefficients of firm and region control variables are emitted

$$\ln\left(Y_{it}\right) = 0.7\ln\left(L_{it}\right) + 0.3\ln\left(K_{it}\right) \tag{14}$$

where Y_{it} denotes the total value-added for firm i in year t, L represents the labour input measured by the total labour costs, and K means the total capital input measured by total fixed assets. Data of these variables come from the FAME database and the Company House dataset. Results of the first mechanism test are shown in column (1). Second, the top and bottom 1% of the sample, in terms of corporate TFP, is shrunk to correct for outliers, with the results shown in column (2). Finally, the author uses the new sample period of 2014–2018 and changes the sample size with results shown in column (3). Results show that for all robustness tests, coefficients of the Brexit indicator (Brexit interaction term) are still significantly negative, justifying the robustness of our empirical results.

7 Conclusion and policy implications

Brexit and its relevant economic uncertainty are believed to have resulted in fluctuations in business environments, local economic growth, and more importantly, corporate productivity in the UK since the 2016 Referendum made the historic decision. Debates on how firms in the UK responded to Brexit have continued for years while relevant studies based on firm-level data are unexpectedly scarce. More importantly, existing studies fail to adopt a scope of regionalism which highlights regional and local features of corporate performance, while providing general analysis on impacts of Brexit on firms in the UK without much robustness. Utilising 2013–2019 data for 123,372 firms in all 22 local councils of Wales, this study analyses how Brexit (defined by the 2016 Brexit Referendum) affects corporate TFP in Wales. Mechanism tests, heterogeneity tests, and robustness checks are also applied. Based on empirical results, the following conclusions can be drawn. First, the fixed-effect analysis shows that in general, Brexit has significant impacts on corporate TFP in Wales, which is supported by a series of robustness tests. Second, spatial heterogeneity analysis reveals that negative impacts of Brexit on corporate TFP are more significant for firms in South Wales where the number of firms are remarkably more than in other regions and business connections with the EU region are also more frequent. Then, the firm heterogeneity analysis reveals that firms with closer business ties with the EU region are exposed to more significant shock due to Brexit with regard to corporate productivity. Third, EU-related trade, FDI inflow, and inward migration are three mechanisms through which Brexit impacts corporate TFP for firms in Wales by lowering the increase rates of all three variables.

These findings raise several policy implications on improvements of economic resilience and business environments in Wales to reduce negative impacts of Brexit on corporate productivity. First, policymakers ought to focus on empirical evidence of potential impacts of Brexit on firms and have a comprehensive estimation of such impacts by also considering its long-term effects and other shocks such as the Covid-19 pandemic and geopolitical conflicts. Several polices can be implemented to enhance the resilience and recovery of corporate productivity in Wales, such as targeted tax cut and subsidies, innovation grants, more investments in skills

training projects, expansion of EU funding programmes, and reduction of trade-related paperwork for SMEs especially with close economic ties with EU countries. These policies are expected to greatly reduce barriers to free trade, FDI inflow, and skilled migration in Wales.

Second, since results of spatial heterogeneity tests show that firms in South Wales are more likely to be impacted by Brexit-driven uncertainty, policymakers in Wales should focus more on corporate performance, financial status, and business resilience for firms in this area and provide additional assistance. Meanwhile, policymakers should also make efforts to optimise the industrial structure in Wales and introduce policies to attract international, especially non-EU investors to de-risk from negative impacts of unstable economic relationship between the UK and EU. It is also important to note that the Welsh government has conducted multiple strategies to attract non-EU FDI and promote international trade, such as introducing plants owned by Hitachi and semiconductor factories from Taiwan. These attempts are believed to bring in new resources of labour and capital, leading to higher-level economic competitiveness and corporate productivity in Wales.

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Declarations

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