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Article

The impact of Brexit on regional productivity in the UK

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The impact of Brexit on regional productivity in the UK

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Abstract: In June 2016, the UK voted to leave the European Union (Brexit). It took until January 2021 before a trade deal was finally agreed and the UK's departure was completed. There have been a number of studies have sought to estimate the impact of Brexit on the UK's regions, mostly using approximations or inferred measures of regional trade. Our focus in this paper is somewhat different, namely on the impact of Brexit regional productivity cross the UK, a key element of the UK Government's concern over geographical inequalities in economic performance. Using a state-of-the-art spatial model, a novel aspect of which is allowing for spatial and temporal spillovers, we are able to estimate the impact of various drivers of regional variations in labour productivity, notably capital per skilled worker, human capital, and goods exports to the EU. We apply the model estimates to simulate the regional impact of post-Brexit reductions in goods exports, finding in particular that in the long run, productivity in the London regions is likely to be less adversely affected than in other regions.

Keywords: regional productivity, Kaldorian theory, exports, impact of Brexit

1 Introduction

In a referendum held on 23 June 2016 by the Conservative Government under Prime Minister David Cameron, by a slim majority of 3.8 percentage points the British public voted to leave the European Union. Just as a Conservative Government had taken the UK into the EU (then the EEC),

some forty-three years earlier, so another Conservative Government was now taking the country out. After more than three years of protracted and at times acrimonious negotiation over the terms of exit, the UK officially left the EU on 31 January 2020.

Opinions differ as to the reasons why the UK joined the EEC back in 1973, and what economic benefits membership was supposed to bring. Crafts (2016) for example, argued that membership helped to raise UK income levels appreciably, in fact by much more than the proponents of EU entry predicted, and that this positive effect stemmed from the impact of increased trade and competition on UK productivity. In his view, Brexit would therefore be risky, and would depend heavily on the nature of the terms agreed and the use of the policy space that would be freed up. In marked contrast, Gudgin, Coutts and Buchanan (2018) argued that contrary to what had been predicted, membership of the EU brought no growth benefits to the UK, that there was no improvement in the country's per capita GDP growth after 1973 compared to previous decades, and that if anything membership had slowed UK growth. They argued that estimates of the impact of Brexit on UK growth have almost all exaggerated the negative consequences and have been flawed in their methodology. For them, the negative impacts of Brexit on the UK economy predicted by many are therefore flawed.

Much of this debate surrounding the likely impact of Brexit on the UK economy has focused on the effects on national growth and national productivity. By comparison, there have been fewer studies of the possible impact on regional and local economic growth. Yet, as a major economic shock to trade (including supply chains), Brexit has the potential to have significant implications for the processes and patterns of regional economic development in the UK (and indeed across regional Europe, and beyond). The importance of trade, and especially of exports, for regional economic prosperity has long been emphasised by economic geographers and regional economists, and any major change or disruption to established patterns of regional trade is of key interest, even concern. One of the key problems confronting assessments of the Brexit shock on the UK regions, however, is the paucity of data on regional and local trade with the EU. Different approaches have been adopted to try to deal with this

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problem. For example, one approach is to use national level input-output tables (in the absence of official inter-regional ones) to estimate local trade linkages (see for example, Thissen et al, 2020); while another is to apply estimates of national sectoral impacts to local industrial structures (for example, Martin and Gardiner, 2019). Both approaches involve approximations based on restrictive assumptions. Perhaps not surprisingly, as a result, findings have differed between different studies, with some suggesting that northern regions and localities in the UK will be most negatively affected (for example, Los et al, 2017; McCann, 2018; Ortega-Argilés and McCann, 2018), whilst other studies suggest a much more complex geographical landscape of potential negative impacts (Dhingra et al, 2017a,b; Martin and Gardiner, 2019; Fetzner and Wang, 2020; Fingleton, 2020a,b).

Our approach in this paper is somewhat different, in two respects. First, we utilise some new official estimates of UK regional and subregional goods exports, differentiated as between EU and non-EU destinations. Second, we are interested in the potential impacts of Brexit on regional productivity paths across the UK. To explore this, we set out a model of regional productivity which is driven by regional output which in turn is influenced by agglomeration effects, regional exports (both EU and non-EU), regional capital stock per skilled worker, and regional human capital. This model has affinities with theorisations of regional growth found in both economic geography and spatial economics, with the addition of regional capital stock per skilled worker (itself a reflection of regional investment). Our formulation is consistent with certain micro-foundations and agglomeration ideas found in both literatures, and embodies the notion of export led regional growth found in the work of Kaldor, as well as Verdoorn-type increasing returns effects. We also allow for the possibility of spatial productivity spillovers and linkages between regions. The model is empirically estimated for the 41 NUTS2 regions in the UK for the period 2001–2019, and is then used to simulate what would happen to regional productivity, both in the short run and the long run, under different scenarios of reductions in goods exports to the EU following Brexit. Of course, Brexit is not the only major shock to have impacted the UK's regional economies in recent years, another major shock being the Global Financial Crisis and associated severe Great Recession of 2007–2010, and more recently the even greater economic downturn associated with the Great Lockdown caused by the Global COVID-19 pandemic and negative knock-on effects of the Ukraine-Russia conflict. Our analysis also differs from previous studies in that our data time series cover the period of the Great Recession, so that any

hysteresis effects of that shock on regional productivity are taken into account in our estimation of our model of regional productivity, and thence the simulations as to the impact of Brexit.

Empirically estimating our model of regional productivity is far from straightforward. For one thing it requires data on regional capital stock. In this paper we use estimates of regional capital stock that we developed in Gardiner, Fingleton, and Martin (2020), but which are updated and improved here. Other data and their construction are discussed in Section 5. Another issue is that a potentially high degree of interdependence (endogeneity) exists between regional output, productivity, investment and employment, which complicates dis-entangling how the uncertainty arising from a drop in exports to the EU caused by Brexit might feed through to impact regional productivity paths. Our estimation methodology, which itself has novel features, is designed to allow for certain aspects of this interdependency. The technicalities of that methodology are discussed in the Appendices to the paper.

Whilst restrictions and uncertainties surround any study concerned with exploring the possible economic effects of Brexit on the UK regions (and indeed on the national UK economy), our approach has the virtue of being founded on an export-based structural model of regional productivity which has theoretical credentials drawn from both the economic geography and spatial economics literatures. Using this model, we find somewhat different impacts, under different scenarios of the fall in exports to the EU, as between the short-run and long-run, especially in relation to London's sub-regions. Our simulations suggest that while the short-run impacts on London's productivity are higher than the impacts in other regions, the long-run impact is lower than elsewhere. This implies that in the long run, Brexit could possibly exacerbate, rather than reduce, the already large productivity differences between London and the other regions, a problem that is currently part of the UK Government's concern to 'level up' the economic geography of the country (H M Government, 2022).

To set the analysis in context, we begin in the next section, with a brief discussion of UK national productivity trends, since national productivity had stalled even prior to the whole Brexit issue, a fact not taken into account in previous studies of the regional impact of Brexit. In the subsequent section, the regional dimension of the productivity problem is outlined. We next develop our model of regional productivity, discuss the data used for its estimation, and then use the model to simulate the potential impact of Brexit. A final section provides a short conclusion and suggestions for further research.

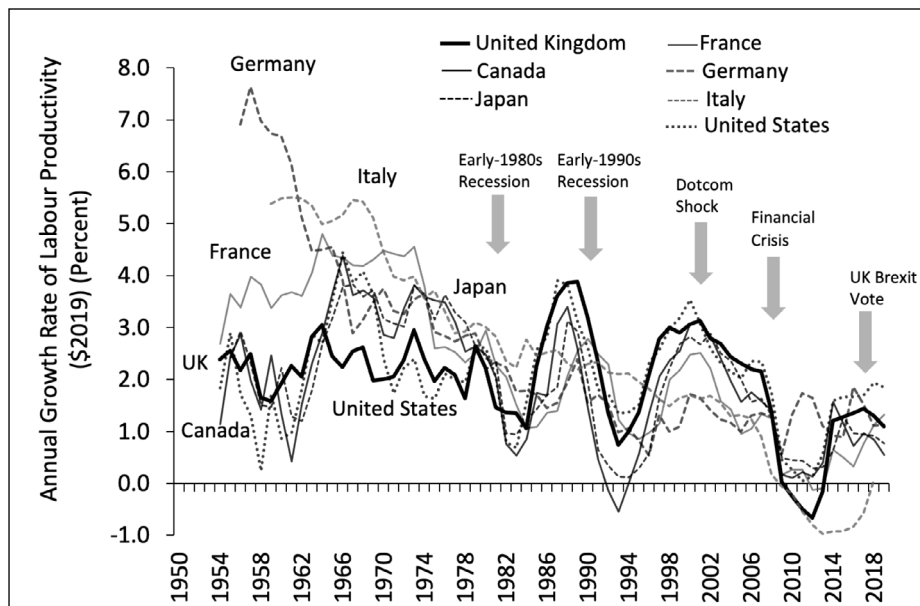


Figure 1: Secular trends and periodic shocks in labour productivity growth: UK and other G-7 Countries, 1950–2019 – five year moving average

Notes: Constructed using data from Conference Board Total Economic Database (Adjusted Version), July 2020 (<https://conference-board.org/data/economydatabase/total-economy-database>) – using a 5-year moving average.

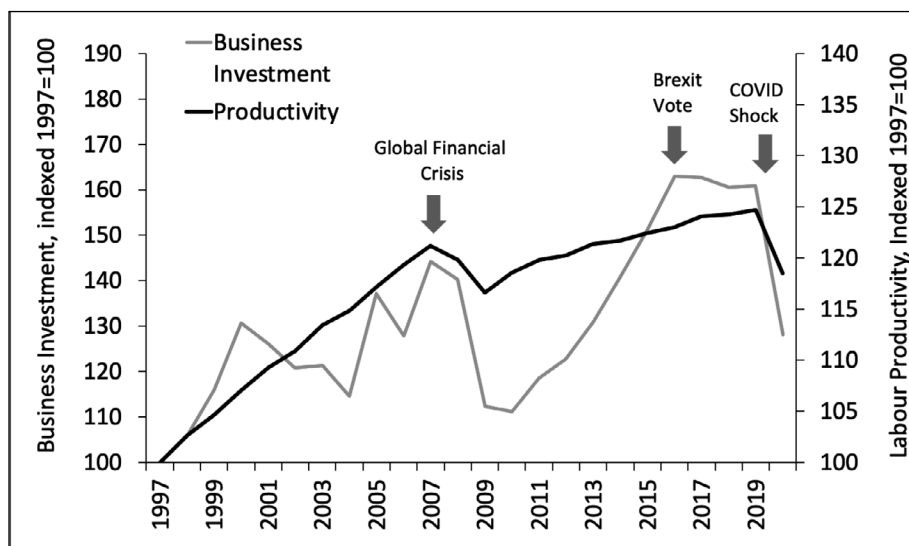


Figure 2: Trends and shocks in business investment and labour productivity, UK, 1997–2020; indexed to 1997=100

Notes: Constructed using data from Office for National Statistics. Business investment is gross fixed capital formation by the private sector, chained volume measure in £million, 2018. Labour productivity is gross value added per worker, which in 2020 includes those workers on furlough due to the COVID-19 pandemic.

The UK's productivity problem: secular slowdown and periodic shocks

The issue of Brexit has not taken place against a particularly favourable context as far as UK productivity is concerned. In the past few years considerable discussion and

debate has surrounded the marked slowdown of the UK's productivity growth since the Global Financial Crisis of 2007–2008. In actual fact, the rate of growth of labour productivity (here defined as output per employed worker) has been on a downward trend since the mid-1980s. Nor is this feature unique to the UK (see Figure 1). A similar secular

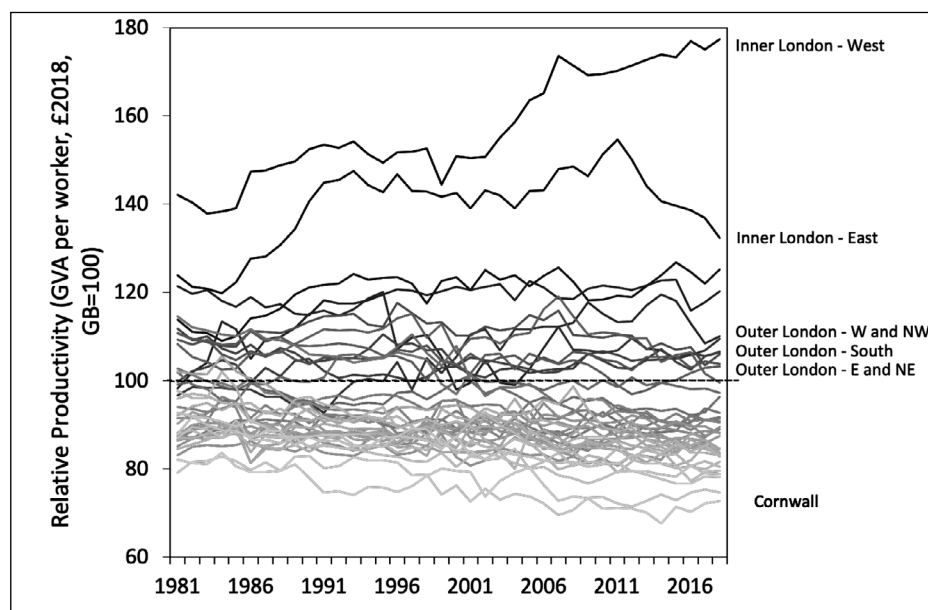


Figure 3: Recent trends in regional labour productivity across the UK, 1981–2018, (NUTS2 Regions), UK=100

Source of data: Cambridge Econometrics. No early data available for Northern Ireland.

slowdown in productivity growth has occurred across all G-7 countries, in some cases extending back to the 1960s. Various hypotheses have been advanced to explain this secular slowdown, both in productivity growth and output growth. Some point to the increasing shift to services that has occurred in the advanced economies, arguing that many services have more limited scope for productivity growth as compared to manufacturing (Baumol, 1967; Baumol, et al, 1985; Williamson, 1991; Kim, 2006).

Others suggest that modern technological advances have failed to feed through to increased productivity (Cowen, 2016; Gordon, 2016; Syverson, 2016). Still others point to declines in public investment as a proportion of GDP (for example, Aschauer, 1989). The jury is still out, however, on the contribution of these and other factors.

The specific case of the UK, the focus of this paper, is shown in Figure 2, which also plots the volume of business investment as well as labour productivity. Both investment and productivity showed a marked drop in response to the Global Financial Crisis induced recession of 2007–2009. But while investment recovered sharply after 2009, the recovery in labour productivity was very subdued by comparison: it would seem that the Great Recession definitely had a negative hysteretic impact on the trend growth rate of labour productivity. What is also interesting is that business investment slowed noticeably around 2016, the year of the Brexit vote, and declined from 2017 onwards, and then especially in 2020 when the COVID-19 pandemic

shock severely disrupted the national economy. Productivity growth shows a similar slowing down after 2016–2017, also followed by a very sharp decline in 2020. Clearly as we move from 2019 into 2020, any impact of Brexit becomes inextricably bound up with, and difficult to disentangle from, the COVID-19 recession.

2 Regional disparities in labour productivity

Regional disparities in labour productivity (output per employed worker) have characterised Britain for at least the past 150 years (Geary and Stark, 2015, 2016). In the 19thC some parts of northern and peripheral Britain – the textile towns of the North West, the shipbuilding centres of Newcastle-Tyneside and Glasgow-Clydeside, and the coal mining areas of South Wales, the East Midlands, Durham, and Lancashire – helped forge the industrial revolution and fuelled the expansion of Empire abroad. But even so, London and the South East had the highest worker productivity in the nation (Crafts, 2005; Geary and Stark, 2015; 2016; Martin and Gardiner, 2018). In the interwar years of the early 20thC, this divide became more pronounced, as northern industrial regions and cities bore the brunt of structural decline and the impact of the Great Depression, while London and the South East attracted the bulk of the new mass consumer goods industries of the period (Scott, 2007).

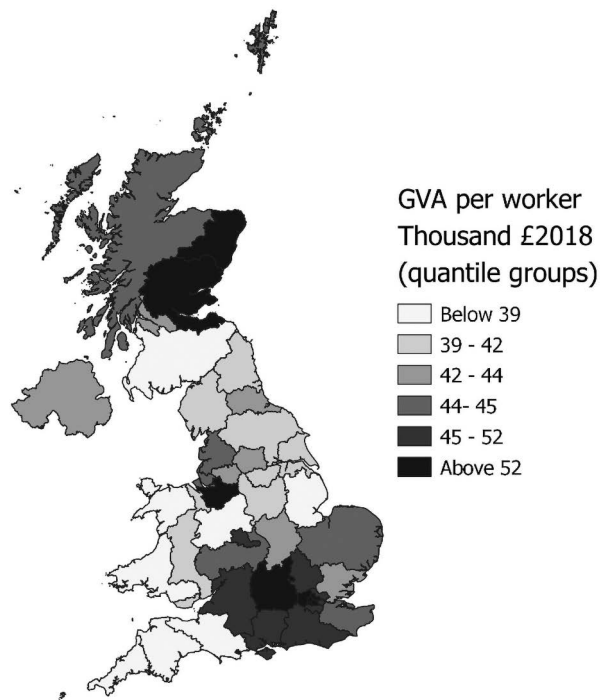


Figure 4: Labour productivity in UK NUTS2 Regions, 2018
Source of data: Cambridge Econometrics

For almost three decades after the Second World War, from 1945 to around the mid-1970s, some slight reduction occurred in the scale of disparity between London-South East and the northern regions. However, from the late-1970s through the 1980s, convergence gave way to renewed spatial divergence. Since 1981 disparities in regional labour productivity have widened significantly, at both the broad NUTS1 regional and the more local NUTS2 geographical scales (Figure 3). In 1981, across the 41 NUTS2 subregions of the UK, there was a 62 percentage point disparity between the highest productivity area of Inner London – West and the lowest productivity region of Cornwall. By 2018 that gap had increased to 105 percentage points (Figure 3). Disparities had also increased even among the sub-regions of London itself. Thus prior to Brexit, marked disparities in labour productivity already existed across the United Kingdom.

These disparities map out a distinctive geography, one that is now all too familiar (Figure 4). The south eastern corner of England, including London, and extending into parts of the Midlands (notably Birmingham), stands out as a high productivity area, in marked contrast to much of the rest of England, Wales and southern Scotland. The major outliers of higher productivity outside of the south-eastern part of England are the Cheshire region, and the Scottish regions of Edinburgh and Aberdeenshire (where the

oil industry is located). It is the low productivity of much of northern England that has become the focus of policy concern in the UK Government's 'levelling up' agenda and its new White Paper *Levelling Up the UK* (HM Government, 2022). A key question, then, is: what determines the uneven geography of labour productivity, and how will Brexit impact that geography? It is to this issue that we now turn.

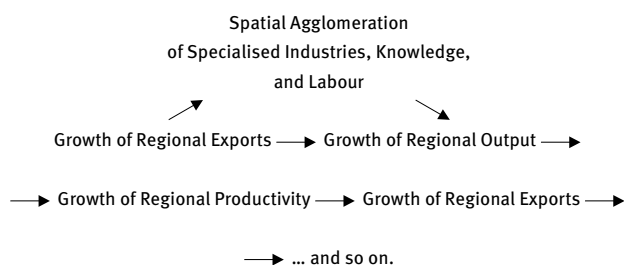
3 Theorising regional productivity disparities

Persistent regional disparities in productivity and economic performance are a characteristic of many countries, including the advanced economies, and are a key dimension of the problem of regional economic inequality analysed by economic geographers and regional economists alike. For instance, in Italy the Mezzogiorno regions have consistently lagged behind the rest of the country in terms of productivity, employment and a host of other, associated, social and economic indicators (Deleidi, et al, 2021). Likewise in Germany, disparities persist between East and West despite unification, and between the south and north of West Germany itself (see Berbée et al, 2022). In the UK, the richer London and South East contrast with the rest of the UK regions in terms of productivity, wages and employment opportunities, and there is little evidence of a significant regional catching-up process as envisioned in conventional, neoclassically-oriented economic theory: to the contrary, what is often labelled the 'north-south divide' has widened significantly in recent years (see, for example, Martin, Sunley and Gardiner, 2020; Martin et al, 2021).

Much contemporary theory in economic geography, urban economics and the 'new economic geography' emphasises the role of externalities due to economic mass (agglomeration) as a reason why some cities and regions perform better than others. Simply stated, a large spatial economic mass not only provides the diversity and variety of inputs needed for production, and large 'home' (local) market opportunities for new enterprises (Jacobs, 1969), but also a concentration of other assets that aid local businesses, such as hard and soft infrastructures, educational centres, skilled labour, institutional networks, and public and private research centres (see Bracalente et al, 2008, for a useful discussion of the sort of agglomeration economies that matter for regional productivity). There is empirical evidence (though not universal) that large, dense cities and regions are more productive than smaller cities or sparsely populated regions. But this is not simply because dense areas have a greater level of inputs

and therefore naturally produce more goods and services than smaller cities, regions or rural areas. It is apparent that they often produce more than is to be expected given the density of economic activity. In other words, there are increasing returns to scale and agglomeration, and this results in higher than anticipated levels of output and productivity in regions containing large dense agglomerations of activity. Accordingly, we typically see increasing returns to economic mass or geographical agglomeration leading to higher levels of local productivity, wages and ultimately labour force participation.

While this focus on agglomeration has become something of a conventional wisdom in contemporary economic geography, regional economics and urban economics, it was a feature of the earlier work undertaken several decades ago by heterodox economists such as Kaldor (1970, 1981, 1985), who argued against neoclassical predictions of a reduction in regional growth differences as a consequence of trade and factor mobility, and in favour of the demand-led nature of economic growth. In his 1985 model, for example, a higher rate of growth of demand for a region's exports will raise the region's level of economic growth. Further, according to Kaldor, export driven growth will both encourage and be enhanced by the geographical agglomeration of the industries concerned, and the increasing returns effects that such agglomeration promotes, including the development of a skilled labour force, dedicated intermediate suppliers, local exchanges of goods, and spillovers of knowledge and technology between local specialised firms.¹ Essentially, the Kaldorian model hypothesises a recursive causal chain of regional export-driven productivity:



¹ For a useful assessment of Kaldor's contribution, see Toner (1999). A Kaldorian-type, export-based theory of regional economic growth, with cumulative causation and path dependent effects is also found in Setterfield (1997). Similar concepts and ideas such as circular causation, positive feedback, endogenous growth, path dependence, historical lock-in and the 'snowball effect' have been extensively used in the regional economics and economic geography literatures (see, for example, Arthur, 1989, 1990; Fingleton, 1994; Glaeser, 2010; Martin, 2017; Martin and Sunley, 1996, 2006).

Part of the stimulus to productivity generated by increased output growth is deemed to arise because output growth both permits and encourages investment, typically in productivity-enhancing capital. Hence, given this chain of effects, if the growth of a region's exports is subject to a downward exogenous shock, such as Brexit, it is likely that this will feed through to a reduction in (or slowdown in the growth of) output, in capital investment, and then in the growth of regional productivity.

Given this background, our entry point in explaining regional productivity time paths is a fundamental relationship linking regional output and labour, in the following way. First, assume *regional output to be a function of geographical agglomeration*:

$$Q_{it} = \phi M_{it}^{\gamma} \quad i = 1, \dots, N, t = 1, \dots, T \quad (1)$$

where Q_{it} is the total level of output in region i at time t , and M_{it} is regional 'economic mass', or level of agglomeration in region i at time t .

Second, *define regional economic mass or agglomeration in terms of labour efficiency units*, so that:

$$M_{it} = L_{it} A_{it} \quad (2)$$

where L_{it} is the aggregate number of employed workers in region i at time t , and A_{it} represents the (average) efficiency of those workers. A value of the parameter γ in equation (1) greater than unity ($\gamma > 1$) would indicate the existence and magnitude of increasing returns effects, so that for example doubling a region's 'economic mass' more than doubles its level of output.² It is easy to show (for example, Fingleton, 2003) that such a relationship relating to output in the final goods and services sectors³ can be derived from micro-economic assumptions typical of the urban and spatial economics literature, namely: a dual market structure, imperfect competition, a constant elasticity of substitution (CES) production function, pecuniary externalities, profit maximisation and a consumer love of variety. We remain neutral regarding the reality of the underlying assumptions leading to equation (1), but as Fingleton (2003) shows, this equation leads to the same equation known as Verdoorn's Law which has a very different theoretical provenance.

² Note that γ is not given a regional subscript. But it could be so given, since the same mass, M , might well result in different externalities in different regions. However, rather than specifying a separate γ for each region, we capture this by controlling for regional heterogeneity in subsequent modelling.

³ Adding output in the final goods and services sector to output in the remainder of the economy to give total output leads to γ in equation (1) somewhere between the γ s for the individual sectors.

Taking logs of equation (1), and substituting equation (2) into equation (1), and rearranging, gives the following relationship for *regional labour productivity (output per employed worker)*:

$$\ln\left(\frac{Q_{it}}{L_{it}}\right) = \ln P_{it} = \ln \frac{\phi}{\gamma} + \left[\frac{\gamma-1}{\gamma}\right] \ln Q_{it} + \ln A_{it}. \quad (3)$$

Hence the level of regional labour productivity P_{it} depends on the level of regional output Q_{it} and on the region's (average) level of labour efficiency A_{it} . With Q_{it} and L_{it} relating specifically to manufacturing, equation (3) is equal to the static Verdoorn Law (as discussed, for example, by Fingleton and McCombie, 1998).⁴

Consider next the determinants of the level of labour efficiency in a given region i , that is $\ln A_{it}$. Our assumption is that this depends on the region's capital stock per skilled worker⁵, $\ln K_{it}$, and on the quality of its human capital, $\ln H_{it}$. Also it is assumed that the region's efficiency is affected by its labour productivity in the previous period, $\ln P_{it-1}$. Additionally, we assume that the level of productivity in other regions influences productivity in region i itself (for example, through supply-chain effects, spillovers of technology, and the like). The level of labour productivity in other regions⁶ is denoted by $\ln P_{it}^R$ and by $\ln P_{it-1}^R$, thus allowing a contemporaneous and lagged geographical spillover effect on a given region's labour productivity. Finally, we allow for three other possibly significant direct influences on regional productivity: first, the cross-region average of output, $\bar{Q}_t$, which takes the same value in each of the N regions at time t , and which is included to control for macro-economic factors (such as national aggregate demand); second, regional goods exports to the EU, $\ln X_{it}^{EU}$; and, third, regional goods exports to non-EU countries, $\ln X_{it}^{nonEU}$. The latter two variables are included in line with Kaldor's model of export-driven regional growth. As we show below, there is a close correlation across regions between exports to the EU and exports

to non-EU markets. Thus it is important to allow for the impact of both on regional productivity in our model.

Hence, bringing all of our hypothesised causal determinants together, the *final structural model of regional productivity* to be estimated empirically is

$$\ln P_{it} = k + \kappa \ln P_{it-1} + \rho_1 \ln P_{it}^R + \theta \ln P_{it-1}^R + \beta_1 \ln K_{it} + \dots \\ \beta_2 \ln Q_{it} + \beta_3 \ln X_{it}^{nonEU} + \beta_4 \ln X_{it}^{EU} + \beta_5 \ln H_{it} + \beta_6 \ln \bar{Q}_t + \varepsilon_{it} \quad (4)$$

where $i=1, \dots, N$ refers to region ($N=41$ NUTS2 regions), and $t=1, \dots, T$ refers to time period (yearly data for 2001–2019). The existence of unobservable effects or omitted variables is represented by the errors $\varepsilon_{it}, i=1, \dots, N$, which embody compound errors. These compound errors can be defined as,

$$u_{it} = \mu_i + v_{it} \quad (5)$$

where $\mu_i, i=1, \dots, N$ is a set of region-specific effects, one for each of the N regions, and assumed constant across time, thus controlling for unobserved time-invariant heterogeneity across regions. The term v_{it} varies both by region and by time, and represents other, unobserved effects.⁷

It is also assumed that the error term ε_{it} embodies spatial dependence or proximity effects among the compound errors, and so will contain the effect of omitted spatially dependent factors and variables (one such could be technology). In the absence of other information, a simpler option is to assume that spatial dependence, as measured by the parameter ρ_2 , can be approximated by a first nearest neighbour spatial moving average error (SMA) process (see Baltagi et al, 2019).⁸

Importantly, to estimate equation (4), we need to control for interdependence effects (endogeneity bias) between productivity, output and capital per worker. To do this we take changes (first differences) of the logged data, so the estimator actually uses *exponential growth*

⁴ Verdoorn's law posits that productivity growth is demand driven, which includes demand for exports, and involves increasing returns effects. It assumes that growth is not supply constrained (see Guilhem and McCombie, 2017).

⁵ The number of workers that have reached at least ISCED education levels 5–8 (ie tertiary education).

⁶ Equal to the matrix product of the N by 1 productivity vector (where N is the number of regions) and the N by N spatial weights matrix, where the weights are the reciprocal of squared interregional distances scaled by the maximum eigenvalue of the matrix of reciprocal of squared distances. This provides acceptable parameter estimates and model diagnostics.

⁷ The assumption is that each μ_i and v_{it} is a random draw from independent and identically distributed distributions thus $\mu_i \sim iid(0, \sigma_\mu^2)$ and $v_{it} \sim iid(0, \sigma_v^2)$ with μ_i and v_{it} independent of each other and among themselves. Given $\sigma_\mu^2 > 0$ there is interregional heterogeneity with μ_i capturing unmodeled fixed effects such as institutional factors, consumer tastes, and attributes associated with location (eg distance from ports).

⁸ Rather than a spatial autoregressive error process, as in Baltagi et al (2014). With positive spatial error dependence, parameter ρ_2 is negative, and vice versa for negative spatial dependence. One advantage of the SMA specification is that it should capture the effect on a region's productivity of local spillovers of regressors.

rates of regional labour productivity rather than regional productivity levels. From this we can recover the parameters $\beta_1, \dots, \beta_6, \kappa, \rho_1, \rho_2$ and θ and test whether they are significantly different from zero. Key aspects of this are the existence, magnitude and extent of increasing returns

effects, as given by $\beta_2 = \frac{\gamma-1}{\gamma}$ (see equation 3). If $1 > \beta_2 > 0$ this means that $\gamma > 1$ and we can assume increasing returns to regional 'economic mass', (agglomeration) as in equation (1). Also, $\beta_1 > 0$ would be indicative of a positive impact of capital stock per skilled worker on productivity. Finally, and crucially, having controlled for the various elements on the right hand side of equation (4), we are especially interested in whether there is a direct effect of regional exports to the EU on regional productivity, as would be indicated by a consistent estimate of $\beta_4 > 0$, since this then allows us to simulate the implications of Brexit on regional productivity under different scenarios of how Brexit might impact on regional exports to the EU.

4 Data and model estimates

Obtaining data with which to estimate the model in (4) was far from straightforward, since official data are not in the precise form required, and had to be manipulated to more fully correspond to the variables used in the model. Regional labour productivity is measured as real output per employed worker. The output data required for this are the regional 'balanced gross value added' (GVA) data prepared by the UK Office for National Statistics (ONS), in constant 2018 prices, deflated using national sectoral deflators. These are workplace based series, and are the best available measure of regional output. To convert these to estimates of labour productivity we use total employment by region, again workplace-based and derived from ONS data supplemented by the Business Registry and Employment Survey (BRES) and the Annual Business Inquiry (ABI).

More problematic are capital stock data. To derive these we first compile annual data on regional investment, derived from an ONS data set released in November 2021, which cover the period 2001 to 2019.⁹ They were deflated using national sectoral deflators derived from ONS investment series. The regional capital stock series were then estimated using the standard Perpetual Inventory Method (PIM), with depreciation rates calculated from ONS capital

consumption data. The other component required to calculate regional capital stock series using the PIM is a starting/initialisation value, and this was defined by taking the national capital stock figure from the ONS and regionally apportioning it according to investment levels in the starting year.

Our measure of the quality of a region's human capital is estimated as the percentage share of each region's working population that has achieved ISCED education levels 5–8 (ie tertiary education). The number of skilled workers were estimated by applying these percentages to the employment series referred to above, which were then used to compute capital stock per skilled worker. With regard to regional exports to the European Union and Non-European Union, we use the estimates produced by the UK's HM Revenue and Customs, which give exports of goods to both EU and non EU countries, by value (£millions).¹⁰ Given yearly aggregate UK goods exports to the EU, and data on regional EU exports for 2017¹¹, aggregate EU exports over 2001–2019 were allotted to the UK regions on the basis of their shares of UK exports for 2017. Thus, estimated region-specific EU export series were calculated on the assumption that regional shares of the UK's exports to the EU remained constant throughout the overall estimation period. The non-EU exports were treated in exactly the same way, starting with UK aggregate non-EU goods exports, and using data on regional non-EU export shares for 2017 to estimate region-specific non-EU export series.

There is a close correlation across regions between goods exports to the EU and non-EU goods exports: regions with a high volume of goods exports to one of these markets also have a high volume of such exports to the other market (see Figure 5). To some extent this is not unexpected, as it reflects the size and sectoral composition of each region's export-orientated goods-producing economic base. There are also, however, regional differences in the orientation of their exporting activities as between the EU and non-EU markets. Figure 6 shows regional goods exports to the EU as a proportion of total regional exports (EU plus non-EU) for 2017. While all regions export goods to the EU, there are clearly regional differences in the degree of dependence on this market. Further, Figure 7 indicates that there is a positive relationship between

⁹ See <https://www.ons.gov.uk/economy/regionalaccounts/grossdisposablehouseholdincome/adhocs/13655regionalgrossfixedcapitalformationitl1anditl22000to2019>

¹⁰ Yearly aggregate UK exports (both EU and non-EU) for the regions of the UK are published by the Office for National Statistics, in the form of seasonally adjusted chained volume measures. We confine our analysis to the regional goods exports only, for although data do exist for service exports, these are as yet experimental.

¹¹ Regional export data were only available for 2016, 2017, 2018 and 2019.

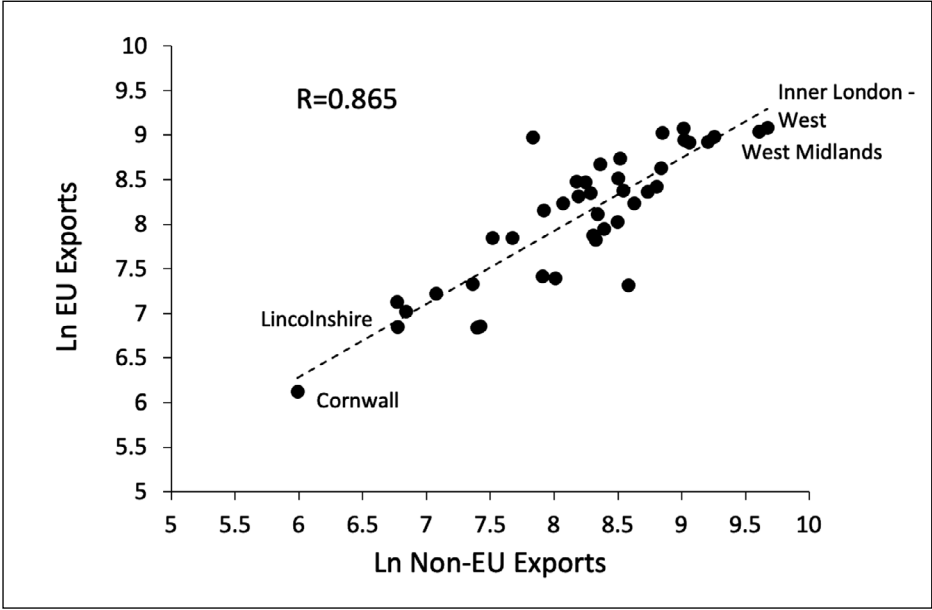


Figure 5: EU and Non-EU goods exports (by value), UK NUTS2 regions, 2017



Figure 6: Regional goods exports (by value) to the European Union as a proportion of total regional goods exports (EU plus non-EU), UK NUTS2 Regions, 2017
Source of data: UK HM Customs and Revenue

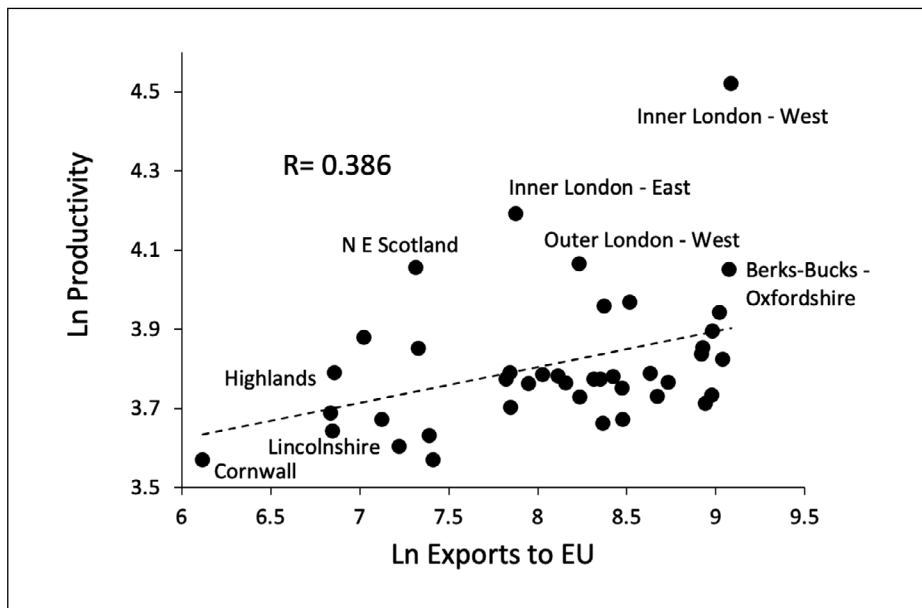


Figure 7: Regional goods exports (by value) to the European Union and regional productivity (GVA per employed worker), UK NUTS2 regions, 2017

regional goods exports to the EU and regional productivity. Our analysis below confirms that productivity is sensitive to variations in these export volumes, and this is a key feature of our simulation analysis of the impact of reduced exports to the EU.

Using these time series data (a total of 779 observations), we apply the Baltagi et al (2019) generalised method of moments, time series, spatial moving average, random effects estimator (GM-TS-SMA-RE for short) to obtain estimates¹² of the parameters $\beta_1, \dots, \beta_6, \kappa, \rho_1, \rho_2$ and θ in equation (4), as given in Table 1. These indicate that regional productivity is positively and significantly affected by

¹² Using different, simpler methods applied to the same spatio-temporal data (spatial error model with fixed regional effects; spatial lag model with fixed regional effects) produced similar conclusions with regard to the significance of the causal variables and support the methods used in the paper (although being much more questionable in terms of their assumptions).

regional output, with increasing returns to scale as theorized, capital stock per skilled worker, regional exports to the EU, regional exports to non-EU countries, regional human capital, and national output. Also regional productivity depends positively on earlier productivity, contemporaneous productivity in surrounding neighbouring regions, but negatively on temporally lagged productivity in surrounding neighbouring regions, as indicated by the estimates of κ , ρ_1 and θ respectively. The significant negative ρ_2 estimate indicates that the model's error terms, capturing unobserved effects, are positively contemporaneously related across regions. Table 1 also gives the short and long-run total elasticities which take into account spatial and temporal spillovers, following the method of LeSage and Pace (2009) and Elhorst (2014). In practice, equation (A3) in Appendix A is used in order to obtain the region-specific long-run impacts of EU export reductions given in Table 2.

Table 1: Estimates of the parameters in equation 4 for 2001–2019

Variable	Param.	Est.	s.e.	Est/s.e	Elasticities	
					Short run total	Long run total
$\ln P_{t-1}$	κ	0.4	0.1002	3.99	0.442	0.645
$\ln P_t^R$	ρ_1	0.372	0.2016	1.84	0.412	0.600
$\ln P_{t-1}^R$	θ	-0.478	0.1474	-3.24	-0.529	-0.77
$\ln K_t$	β_1	0.177	0.0752	2.35	0.196	0.285

Variable	Param.	Est.	s.e.	Est/s.e	Elasticities	
					Short run total	Long run total
$\ln Q_t$	β_2	0.369	0.1103	3.35	0.409	0.595
$\ln X_t^{nonEU}$	β_3	0.082	0.0205	3.99	0.091	0.132
$\ln X_t^{EU}$	β_4	0.036	0.0149	2.39	0.04	0.058
$\ln H_t$	β_5	0.126	0.0781	1.62	0.14	0.204
$\ln \bar{Q}_t$	β_6	-0.271	0.0799	-3.4	-0.3	-0.437
Error process						
	ρ_2	-0.2488	0.0569	-4.37 ¹³		
	σ_μ^2	0.0465				
	σ_v^2	0.0003				

Notes: Total number of original observations – 19 time periods and 41 regions = 779. After taking first differences (changes) in the logged variables (see Appendix A), and using lagged values of the instrumental variables (see Appendix B), the number of observation is 17 time periods and 41 regions = 697.

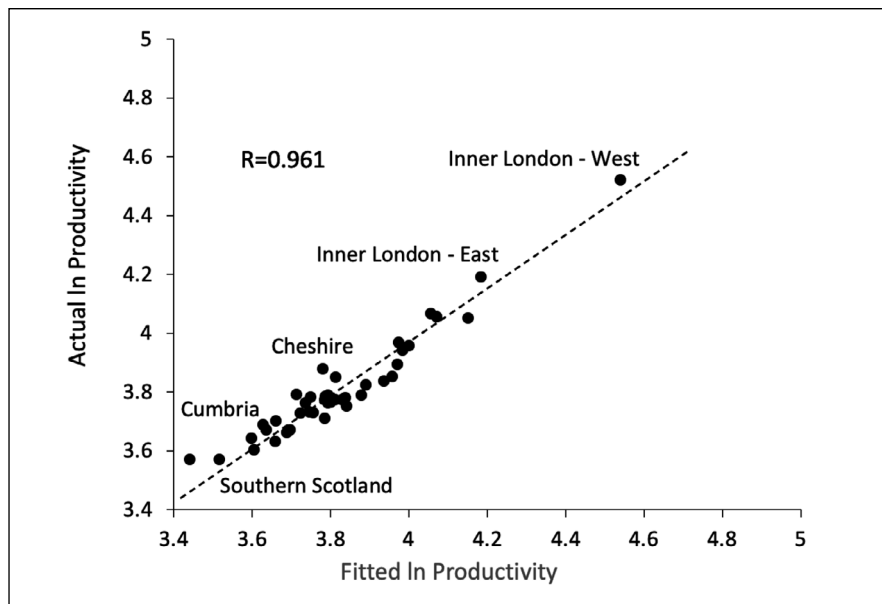


Figure 8: Predictive performance of equation 4

Appendix B gives some diagnostic indicators supporting the model estimates (Table B1). This shows that the parameter estimates are consistent with stationarity and dynamic stability. The Kaldor export-driven cumulative causation model (Dixon and Thirlwall, 1975a,b, 1978) will show stabilized growth rates of productivity but diverging levels. In our case, growth rates are a feature of the estimation method, since this requires the logged data to be differenced. The estimated parameters are then

inserted into the levels equation, which is equation 4. So using equation 4, changing the levels of exports to the EU changes the level of productivity, not the growth rate. Recursive estimation leads to long run outcomes in which the levels stabilize and long run growth rates go to zero.

¹³ Based on 100 Bootstrap replications, with null distribution mean = -0.0004 and null distribution standard error = 0.0569

Nevertheless, we could obtain divergence of levels if the estimated parameters had violated the dynamic stability conditions given in Table B1. But our estimates do not do violate the stability condition. The basic point is that for the future we are assuming everything, apart from exports to the EU, stays the same, as this greatly facilitates and simplifies the measurement of simulated regional trade impacts. But as we know, everything will not stay the same, and in reality stability will be violated and we could then get regional divergence in productivity.

The estimates produce fitted values over the estimation period 2001 to 2019 that are similar in value to the observed regional productivity levels. Figure 8 gives the observed and predicted log productivity across the 41 UK regions for the year 2019, illustrating that the model produces quite accurate predictions.

5 Simulating the impact of Brexit

We now apply the Table 1 parameter estimates to the prediction and simulation equation (A3) in Appendix A to estimate the impact of leaving the EU. Accordingly, we estimate regional productivity under various scenarios assuming that the decision to leave the EU will reduce trade in goods due to increased post-Brexit trade barriers and frictions, under different scenarios as to the scale of that reduction.

Table 2 shows the long-run effect of a 1 % reduction in goods exports to the EU from each region. This is not a prediction, because the assumption is that the drivers of productivity other than exports and their respective elasticities remain at their 2019 levels. So we are simulating what would happen were exports to be permanently reduced by 1 %, holding other causal effects on productivity constant. Note that the mean of the region-specific effects is equal to the long-run total elasticity given in Table 1. We also estimate the effect on each region of a 15 % and 33 % reduction in goods exports from each region to the EU, with these percentages chosen to facilitate comparison with the estimation in a very recent report by the UK's Office for Budget Responsibility (OBS, 2021, 2022) which assumed that (total) UK imports and exports will eventually both be 15 % lower than had we stayed in the EU. A 15 % reduction in goods exports to the EU is based on an assumption that goods exports to the EU and non-EU countries will decline equally. However a 33 % reduction in EU goods exports assumes that all of the decline in total goods exports is attributable to EU exports, which account for about 45 % of total goods exports¹⁴.

Assuming 15 % reduction in EU exports gives a mean percentage reduction in productivity across all regions of -0.93% . A 33 % reduction is assumed to cause a -2.28% reduction in productivity, which is somewhat below the OBS figure of a 4 % reduction in long-run potential productivity assuming total exports fell by 15 %. Although the long-run 'steady state' productivity levels vary considerably according to region $i=1, \dots, N$, the effects of trade reductions are quite similar across regions, with the exception of the London subregions, where the impact is clearly below the average. This reflects central London's relatively low regional goods exports (by value) to the European Union as a proportion of its total goods exports (EU plus non-EU), as highlighted by Figure 6.

Table 2 also gives the short run effects of different reductions of the levels of UK-EU goods export trade. These are also obtained by applying equation A(3) and pertain to a specific point in time. However, with a temporary reduction in UK-EU trade at just one point in time, following an initial one-off downward shock, each region's productivity path will gradually re-join its previous pre-Brexit path. So, in a sense the short run effects can be misleading because if the shock to trade is to be a permanent one, they only give a partial picture of the consequences. In contrast, the long run effects are based on the assumption that the reduction in the trade is a permanent phenomenon.

Table 2 shows that the short run effects are smaller, with the mean percentage reduction in productivity as a result of 33 percent reduction in EU exports equal to -1.57% , compared with the mean long run effect of -2.28% . For London regions, while the long run effect of a permanent reduction in trade is less than for other regions, the short run effects consistent with a temporary reduction in UK-EU goods export trade would affect productivity in London more severely than in other regions. So, it would be misleading to consider the above average short run impacts for London as the definitive consequences of assumed Brexit-induced reductions in trade. The implication is that London would bounce back more readily than other regions from a relatively severe short-run impact of reduced EU export trade, and in the long-run would be less adversely affected than other regions. This finding resonates with other studies that find London to have a higher economic resilience than other UK cities and regions, in that while it may be no less vulnerable to major shocks such as recessions, it recovers from them more strongly and rapidly than other regions (see for example, Martin and Gardiner, 2021).

¹⁴ According to HM Revenue and Customs (11/02/2022), in the year to December 2021 EU goods exports amounted to £155bn and non-EU

goods exports were £185bn. A 15 % reduction in total exports attributed entirely to EU trade in goods would cause EU goods exports to fall by £51bn, or approximately 33 %.

Table 2: The simulated effects on productivity of various reductions in goods exports to the EU (using equation A3 in Appendix A)

	Long run			Short run		
<i>Reduction in Goods Exports to EU</i>	<i>–1 %</i>	<i>–15 %</i>	<i>–33 %</i>	<i>–1 %</i>	<i>–15 %</i>	<i>–33 %</i>
Tees Valley and Durham	–0.0591	–0.9514	–2.3281	–0.037	–0.5962	–1.4627
Northumberland and Tyne and Wear	–0.0594	–0.9555	–2.338	–0.0366	–0.5905	–1.4489
Cumbria	–0.0592	–0.9536	–2.3334	–0.0368	–0.5932	–1.4555
Greater Manchester	–0.058	–0.9338	–2.2854	–0.0385	–0.6209	–1.523
Lancashire	–0.0586	–0.943	–2.3078	–0.0377	–0.6081	–1.4919
Cheshire	–0.0582	–0.9364	–2.2917	–0.0383	–0.6175	–1.5147
Merseyside	–0.0584	–0.9398	–2.3	–0.038	–0.6127	–1.503
East Yorkshire and Northern Lincolnshire	–0.059	–0.9506	–2.3261	–0.0371	–0.5978	–1.4666
North Yorkshire	–0.0588	–0.9474	–2.3183	–0.0373	–0.6019	–1.4767
South Yorkshire	–0.0582	–0.9375	–2.2944	–0.0382	–0.6158	–1.5107
West Yorkshire	–0.0583	–0.938	–2.2955	–0.0381	–0.6151	–1.5089
Derbyshire and Nottinghamshire	–0.0585	–0.9412	–2.3034	–0.0379	–0.6111	–1.499
Leicestershire, Rutland and Northamptonshire	–0.0588	–0.9459	–2.3147	–0.0376	–0.606	–1.4867
Lincolnshire	–0.059	–0.9503	–2.3255	–0.0371	–0.5987	–1.4688
Herefordshire, Worcestershire and Warwickshire	–0.0586	–0.9431	–2.3079	–0.0378	–0.6088	–1.4936
Shropshire and Staffordshire	–0.0585	–0.9425	–2.3064	–0.0378	–0.6092	–1.4946
West Midlands	–0.0584	–0.9399	–2.3002	–0.038	–0.6132	–1.5042
East Anglia	–0.0592	–0.9529	–2.3318	–0.037	–0.5966	–1.4636
Bedfordshire and Hertfordshire	–0.0582	–0.9364	–2.2917	–0.0391	–0.6305	–1.5465
Essex	–0.0585	–0.9412	–2.3034	–0.0386	–0.6218	–1.5252
Inner London – West	–0.0473	–0.7627	–1.8689	–0.0655	–1.0538	–2.5767
Inner London – East	–0.0469	–0.7564	–1.8537	–0.0662	–1.0644	–2.6024
Outer London – East and North East	–0.0532	–0.8572	–2.0991	–0.0525	–0.8452	–2.07
Outer London – South	–0.0539	–0.8683	–2.1262	–0.0504	–0.812	–1.989
Outer London – West and North West	–0.0536	–0.8627	–2.1124	–0.0516	–0.8306	–2.0342
Berkshire, Buckinghamshire and Oxfordshire	–0.0586	–0.9427	–2.3071	–0.0381	–0.615	–1.5086
Surrey, East and West Sussex	–0.0584	–0.9407	–2.3022	–0.0387	–0.6243	–1.5313
Hampshire and Isle of Wight	–0.059	–0.9504	–2.3257	–0.0373	–0.6012	–1.475
Kent	–0.0588	–0.9472	–2.3178	–0.0379	–0.6105	–1.4976
Gloucestershire, Wiltshire and Bristol/Bath area	–0.059	–0.9498	–2.3243	–0.0372	–0.6	–1.4721
Dorset and Somerset	–0.0593	–0.9546	–2.336	–0.0367	–0.5926	–1.4539
Cornwall and Isles of Scilly	–0.0596	–0.9598	–2.3486	–0.0363	–0.5848	–1.435
Devon	–0.0595	–0.9575	–2.3429	–0.0365	–0.5882	–1.4431
West Wales and The Valleys	–0.0593	–0.9541	–2.3347	–0.0368	–0.5928	–1.4544
East Wales	–0.059	–0.9503	–2.3254	–0.0371	–0.5982	–1.4675
North Eastern Scotland	–0.0597	–0.9607	–2.3508	–0.0362	–0.5834	–1.4314
Highlands and Islands	–0.0597	–0.9613	–2.3522	–0.0361	–0.5826	–1.4295
Eastern Scotland	–0.0595	–0.9583	–2.3449	–0.0364	–0.5866	–1.4392
West Central Scotland	–0.0595	–0.9577	–2.3435	–0.0364	–0.5873	–1.4411
Southern Scotland	–0.0594	–0.9569	–2.3414	–0.0365	–0.5886	–1.4442
Northern Ireland	–0.0597	–0.9612	–2.3518	–0.0361	–0.5829	–1.4302

Of course, the above analysis and simulated impacts refer to goods exports, and do not include the effects of Brexit on service exports. A key aspect of this issue concerns the implications of Brexit for financial services, especially given the importance of this sector in London's economy. The city's financial services were all but excluded from the UK-EU trade deal in December 2020, and have yet to see a deal on equivalence (the status the EU grants to third countries allowing them to operate fully in Europe). Stock market trading in London dropped

by 34 percent within a month of the UK leaving the EU; it then recovered strongly until the onset of the COVID-19 pandemic. Globally, London remains dominant in several markets, including foreign exchange and derivatives, and is still the world's second-biggest financial centre behind New York, far ahead of its European rivals. And while there has been a shift of some financial services employment and assets to Paris, Dublin and Luxembourg, the numbers thus far have been very small. According to industry specialists, any future move of financial services

activity out of London to centres in the EU will be slow rather than dramatic. The long run impact of Brexit on the productivity of London's financial nexus is thus difficult to predict.

6 Discussion

Our attempt to measure the impact of Brexit on regional productivity variations across the UK is based on a dynamic spatial panel model with a specification stemming from early insights regarding the role of diversity in the urban economy, and spatial economic theory with micro-economic assumptions, each of which is consistent with a fundamental equation relating the level of output in a region or city to its economic mass or agglomeration. By measuring economic mass in terms of the size of the labour force, we obtain a relationship between productivity and output which is consistent with the static Verdoorn Law, which is a familiar concept in Kaldorian post-Keynesian analysis. Moreover, we obtain a model which shows that regional variations in labour productivity across UK regions over the period 2001–2019 depend on the regional levels of output, human capital, exports of goods to both the EU and to the rest of the world, and capital stock per skilled worker, as predicted by the theory outlined in Section 4. In addition, there appear to be significant productivity spillover effects operating across time and space, especially between spatially proximate regions. These results are of value in their own right, in that they seem to have identified some key determinants of regional variations in productivity, that provide an impetus for further work along these lines.

But they also allowed us to use our pre-Brexit estimated model to explore the potential negative impact of post-Brexit downturns in regional exports to the EU under different scenarios. Overall, the results show that a reduction in goods exports to the EU has a negative impact on regional productivity, with the size of the impact increasing with the scale of the decline in export volumes, and whether we are interested in short run or long run effects. The cross-region long-run steady state productivity levels vary, with London at the highest level, but the estimated Brexit impacts are surprisingly similar, with the exception of London regions, which generally have the smallest percentage reduction in productivity. This suggests that in the long run Brexit could possibly exacerbate, rather than reduce, the already large productivity differences between London and the other regions, a problem that is currently part of the UK Government's

concern to 'level up' the economic geography of the country (H M Government, 2022).

It is interesting that our findings, notwithstanding that they are based on a model holding the effect of other factors constant, including non-EU exports, echo the conclusion of the aforementioned report by the UK's Office for Budget Responsibility (OBS), that total UK imports and exports will eventually both be 15 per cent lower than had we stayed in the EU. Our estimates of the reduction in potential long-run potential productivity, in this case across Britain's regions, may be lower than the OBR's national estimate, but they point equally to the possibility of a permanent negative impact resulting from the UK's withdrawal from the EU.

Of course, in practice, how future regional trends in productivity in the UK actually evolve over the next decade or so will depend on many factors, including how the specific trading arrangements with the EU develop, the success with which the UK is able to strike new favourable bilateral trade deals with non-EU countries, how supply-chains develop, and other factors.¹⁵ And of course, investment by firms, and hence capital stock, could change for a variety of reasons. Regional differences in the quality (educational-skill level) of human capital tend to change only slowly over time (and in this respect are tantamount to a regional fixed effect), although the impact of Brexit on the in-migration of skilled foreign workers into the UK may well impart instability into those regional differences, since prior to Brexit London and the surrounding South East had the highest proportions of EU migrants in their labour forces (see Wadsworth et al, 2016).¹⁶ We have not included labour migration effects in our model, though they will in part be subsumed under our human capital variable: the impact of migration on regional productivity is an issue that future work should explore. But certainly as far as the impact of Brexit on UK exports to the EU is concerned, there is growing concern at the present time that Brexit is particularly hitting the export activity of UK SMEs.¹⁷ The approach set out in this paper provides a potentially useful framework for monitoring the evolving impact of Brexit on the UK's regions, provided the rele-

¹⁵ Including the economic after-effects of the global COVID pandemic (especially on supply chains), the impact of Russia's invasion of Ukraine, the transformative effects of progress towards a net zero carbon economy, and the spread of AI through industries and services.

¹⁶ Though in 2021 the UK Government has introduced a skilled worker visa route for entry into the country for workers from the EU and non-EU.

¹⁷ See, for example, <https://www.cityam.com/brexit-drop-in-uk-eu-trade-hits-smaller-businesses-as-they-are-forced-to-shun-exports/>.

vant data are collected and made available. In particular, the availability of annual estimates of regional trade (for both goods *and* services) will be crucial. Detailed time series trade data (both intra-national and extra-national trade) are in fact critical to any coherent theory of regional development, yet are all too often not available to subject such theory to empirical test. As the availability of sub-regional trade data continue to improve, the post-Brexit period itself lengthens, and UK trade arrangements and deals evolve over the next few years, then proper *ex post* analyses of the impacts of Brexit on regional productivity will become possible. In the meantime, however, simulation studies such as that conducted in this paper certainly offer some useful – and potentially worrying – insight into what could happen, under particular assumptions.

Appendix A: The calculation of short and long-run elasticities

Table 1 gives the short and long-run elasticities which take account of the spillover effects embodied in our specification. These are obtainable from N by N matrices of derivatives using the N by N matrices $\mathbf{W}$, $\mathbf{B}$, $\mathbf{I}$ and $\mathbf{C}$ where $\mathbf{W}$ is the regional connectivity matrix $\mathbf{I}$ is an identity matrix, $\mathbf{B} = (\mathbf{I} - \hat{\rho}_1 \mathbf{W})$ and $\mathbf{C} = (\hat{\kappa} \mathbf{I} + \hat{\theta} \mathbf{W})$, with equation (A1) giving the long-run elasticities and equation (A2) the short-run elasticities. Equation (A1) gives the true derivative of $\ln P_{it}$ with respect to $\ln x_{ik}$ for $i=1, \dots, N$, where k indicates regressor k and $\tilde{\beta}_k$ is the parameter estimate for regressor k . So the true elasticities for $\ln X_t^{EU} = \ln x_{ik}$ are given by $\tilde{\beta}_k = \hat{\beta}_4$. These matrices of derivatives provide measures of the direct, indirect and total effects of a unit increase in $\ln X_t^{EU}$. However in order to provide a summary measure, following LeSage and Pace (2009), means are taken across the matrices. Thus, the direct long-run effect of a persistent unit increase in $\ln X_t^{EU}$ as t goes to infinity is equal to the mean of the leading diagonal of the matrix given by equation (A1). The total effect is equal to the mean column sum of the matrix of derivatives and the indirect effect is equal to the total effect minus the direct effect. The short-run effects are calculated in an identical way via equation (A2) but pertain to an increase in $\ln X_t^{EU}$ at time t .

$$\begin{bmatrix} \frac{\partial \ln P_{1t}}{\partial \ln x_{1k}} \dots \frac{\partial \ln P_{1t}}{\partial \ln x_{Nk}} \\ \dots \\ \frac{\partial \ln P_{Nt}}{\partial \ln x_{1k}} \dots \frac{\partial \ln P_{Nt}}{\partial \ln x_{Nk}} \end{bmatrix} = [-\mathbf{C} + \mathbf{B}]^{-1} \tilde{\beta}_k \mathbf{I} \quad (\text{A1})$$

$$\begin{bmatrix} \frac{\partial \ln P_{1t}}{\partial \ln x_{1k}} \dots \frac{\partial \ln P_{1t}}{\partial \ln x_{Nk}} \\ \dots \\ \frac{\partial \ln P_{Nt}}{\partial \ln x_{1k}} \dots \frac{\partial \ln P_{Nt}}{\partial \ln x_{Nk}} \end{bmatrix}_t = \mathbf{B}^{-1} \tilde{\beta}_k \mathbf{I} \quad (\text{A2})$$

An alternative, more transparent, more practical and entirely equivalent approach to using equations (A1) and (A2) to obtain the total elasticities is given by the counterpart of equation (4), which is the empirical prediction and simulation equation

$$\begin{aligned} \ln \hat{P}_{it}^A &= \hat{\kappa} + \hat{\kappa} \ln \hat{P}_{it-1} + \hat{\rho} \ln \hat{P}_{it}^R + \hat{\theta} \ln \hat{P}_{it-1}^R + \hat{\beta}_1 \ln K_{it} + \\ &\hat{\beta}_2 \ln Q_{it} + \hat{\beta}_3 \ln X_{it}^{\text{nonEU}} + \hat{\beta}_4 \ln X_{it}^{EU} + \hat{\beta}_5 \ln H_{it} + \hat{\beta}_6 \ln \bar{Q}_t + \\ &\hat{u}_{it} - \hat{\rho}_2 \sum_{j=1}^N m_{ij} \hat{u}_{jt} \end{aligned} \quad (\text{A3})$$

which uses the method of Baltagi et al (2019) to obtain estimates of the compound errors u_{it} . Given future values over $\tau = T+1, \dots, T+s$ of the right hand side regressors one can apply equation (A3) to give predicted productivities up to s steps ahead. Additionally, Fingleton and Szumilo (2019) show that one can estimate both total long-run and short-run elasticities by simulating the impact of changing an individual variable holding other variables constant with their values at $\tau = T$. Thus if $\ln X_{it}^{EU}$ increases temporarily at time τ by $\Delta \ln X_{it}^{EU} = \log(1.01)$, so that X_{it}^{EU} increases by 1% across all N regions, one obtains the comparator to (A3) $\ln \hat{P}_{it}^B, i=1, \dots, N$ where $\ln \hat{P}_{it}^B$ is determined by the same variables as shown in equation (A3), and so is identical to equation (A3) but with $\ln X_{it}^{EU} + \Delta \ln X_{it}^{EU}$ in place of $\ln X_{it}^{EU}$. It follows that the mean total short-run elasticity giving the ephemeral effect on log productivity of a unit change in log exports is

$$\frac{d \ln P}{d \ln X^{EU}} = \sum_{i=1}^N (\ln \hat{P}_{it}^A - \ln \hat{P}_{it}^B) / N. \quad (\text{A4})$$

The long-run elasticity assumes a permanent increment so that $\Delta \ln X_{it}^{EU} = \log(1.01)$, $i = 1, \dots, N$, $\tau = 1, \dots, E$ where E is a large number. The mean total long-run elasticity is then given by iterative calculation of $\ln \hat{P}_{it}^A$ and $\ln \hat{P}_{it}^B$ for $\tau = 1, \dots, E$ giving

$$\frac{d \ln P}{d \ln X^{EU}} = \sum_{i=1}^N \left(\ln \hat{P}_{iE}^A - \ln \hat{P}_{iE}^B \right) / N. \quad (A5)$$

From this the assumptions underpinning these elasticities become clear. They require parameter estimates that are consistent with stationarity and dynamic stability, and for long-run elasticity other variables remain constant to time E .

In practice, in order to obtain region-specific long-run impacts of EU export reductions as given in Table 2, we therefore calculate

$$\begin{aligned} &\% \text{ reduction in productivity in region } i = \\ &-100(1 - \exp(\ln P_{iE}^B) / \exp(\ln P_{iE}^A)) \end{aligned} \quad (A6)$$

where in the calculation of $\ln \hat{P}_{iE}^B$, $\Delta \ln X_{it}^{EU} = \log(0.99)$, $\log(0.85)$ or $\log(0.67)$ according to whether reductions in trade of 1%, 15% or 33% are being considered and $\ln \hat{P}_{iE}^A$ are the set of long run equilibrium productivities which would occur were there no effect on each region's goods exports to the EU due to Brexit. Likewise the total short-run region-specific effects are given by equation (A3) using $\ln \hat{P}_{it}^A$ and $\ln \hat{P}_{it}^B$.

Appendix B: Estimation issues

A feature of our approach is the treatment of the right-hand side variables, none of which are assumed to be exogenous. In common with Deleidi et al (2021), we are aware of the potential endogeneity bias associated with the productivity growth modelling. In their case, they approach this via panel structural vector autoregressive modelling (P-SVAR). In our case we apply the Baltagi et al (2019) generalised method of moments, time series, spatial moving average, random effects estimator (GM-TS-SMA-RE) which involves first differences¹⁸ and which uses the orthogonality conditions of Arellano and Bond (1991) as well as extra spatial

orthogonality conditions and which accounts for the SMA structure of the disturbances using a similar approach to that of Fingleton (2008a,b). In order to eliminate bias in the estimates of the model parameters due to potential endogeneity, such as for example due to feedback from the level of productivity to each of the right-hand side variables of equation (7), they are replaced by instrumental variables which satisfy the orthogonality conditions, in other words they are uncorrelated with the differenced errors $\Delta \varepsilon_{it}$.

A useful feature of the Arellano and Bond (1991) and GM-TS-SMA-RE estimators is that the instrumental variables for endogenous regressors can be simply their earlier time-lagged levels, provided the first differenced errors are serially uncorrelated (see Bond, 2002). While the first differenced errors at time t and $t-1$ will naturally be correlated, for consistent estimation we rely on the assumption of zero second order serial correlation in the differenced errors, that is the first differenced errors at time t and $t-2$ are independent. If this assumption holds, this means that we can use the levels of the regressors up to lag $t-2$ as instruments. A test of the assumption is given by Arellano and Bond (1991) who provide a test statistic m_2 which is asymptotically distributed as a normal distribution with mean zero and variance equal to 1, under the null hypothesis of no second-order serial correlation. However the distributional assumptions have a theoretical requirement that errors are not correlated across individual units, in our case the UK regions. To counter this, following Le Gallo and Fingleton (2019), we first filter the errors to remove spatial dependence. Given non-rejection of the null hypothesis of no second-order serial correlation, the lagged regressors as instruments for the endogenous variables lead to consistent model parameter estimates. Table B1 gives the outcome for the m_2 test statistic.

One major problem with the use of time-lagged regressors as (internal) instruments is that the number of instruments can become too large, and thus downwardly bias parameter standard error estimates and lead to overfitting endogenous variables biasing estimates towards those obtained assuming exogeneity. In order to reduce instrument proliferation, use is made of external instruments, in the classic one column for each instrumenting variable layout, for right hand side variables (except those endogenous variables involving $\ln P_t$) rather than employing exploded lagged values. We believe our solution is somewhat novel and could be generally useful. First we adopt the standard approach for the internal instrument set involving the $\ln P_t$ variables so that there is one instrument for each endogenous variable, time period, variable, and lag distance. Second, for the remaining right hand side variables we generate orthogonal external synthetic

¹⁸ First differences of logs equal exponential growth rates, so the estimated coefficients of the model are based on a model of productivity growth on output growth etc.

instruments adapting the method of Le Gallo and Páez (2013). Since these are based on the fitted values of first stage regressions of the “endogenous” regressors and their spatial lags on eigenvectors derived from the symmetrical regional contiguity matrix, which is completely independent of the level of productivity, they are *de facto* exogenous variables and thus appropriate external instruments.

Stationarity and dynamic stability are determined by the κ, ρ_1 and θ estimates combined, in the

form e_W^{max} which is the maximum eigenvalue of $\mathbf{A} = (\mathbf{I} - \hat{\rho}_1 \mathbf{W})^{-1} (\hat{\kappa} \mathbf{I} + \hat{\theta} \mathbf{W})$. Table B1 indicates that the model estimates are consistent with stationarity and dynamic stability. Thus, we know that one of the conditions for the existence of a long run total elasticity has been satisfied (see also Elhorst, 2001, 2014, Parent and LeSage, 2011, 2012, Debarsy et al., 2012, and Lee and Yu, 2010).

Table B1: Diagnostics for the GM-TS-SMA-RE model

test	diagnostic	requirement	Outcome
Second-order serial residual correlation	Arellano and Bond m_2 , ref N(0,1)	Should not differ significantly from zero	−0.4447
Dynamic stability and stationarity	e^{max} = maximum absolute eigenvalue of $\mathbf{A}$	Stationarity and dynamic stability if $e^{max} < 1$	0.5841

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