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Modelling the effects of Brexit on the British economy

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Abstract: We estimate the short run effects of Brexit border disruption on the UK economy. We estimate a structural VAR for the UK where Brexit effects are identified by the dates of Brexit events, the referendum and the exit from the single market. We find evidence of short run effects of Brexit: temporary effects on GDP, exports and imports (slightly negative),and on inflation and interest rates (slightly positive). These effects are consistent with modest disruption from introducing a border with the EU- a border due to be made barrier-free and seamless by the UK-EU Trade and Cooperation Agreement. Previous work using other countries as comparators is vulnerable to identification difficulties. We also survey earlier modelling work on the long run effects of evolving policies of free trade, UK-sourced regulation and liberalised immigration. Models of long run trade suggest the emergence of substantial gains.

Introduction

There has been a lot of recent comment in the UK media to the effect that Brexit has damaged the UK economy and its trade, for example, from LSE's Dr. Swati Dhingra in oral evidence to the Commons Treasury Committee[1], and also recent comments in the FT[2]. Yet these claims are puzzling, given the numerous shocks that have hit both the world generally and the UK in particular, including Covid and the Ukraine war- for an opposing view, see Gudgin et al, 2022. How can it be possible to discern a Brexit effect in all this volatility? The issue when so many

[1] https://committees.parliament.uk/committee/158/treasury-committee/publications/oral-evidence/ -Nov16

[2] https://www.ft.com/content/e39d0315-fd5b-47c8-8560-04bb786f2c13

shocks are impacting on the economy, is to sort out the wheat from the chaff and identify the Brexit element in them all. In principle, the way to do this is to set out a ‘normal relationship’ determining the economic variables of interest and then to identify the point of time at which the Brexit element intervened; this key date of Brexit arrival then allows us to identify the Brexit effect mathematically as a shift in the relationship definitely due to Brexit owing to its coinciding with that date. This ‘event study’ analysis depends critically on the ability to tie the effects of Brexit to a particular date or dates. Because there are so many other shocks occurring before and after this event, two questions arise. One is that of identification: could these other shocks have had effects at these times? We can attempt to answer this by either excluding or somehow controlling for these other shocks. Another question is whether any estimated effect is sufficiently large for us to be confident it could not have occurred by chance, due to general shock volatility, rather than due to the event- here Brexit. We judge this in a standard way, as what could occur with up to 95% probability; if the estimated effect exceeds this, it would only have a 5% chance of occurring and so we consider that the event most probably had an effect.

Accordingly, we have looked carefully for such effects on the relevant UK data; they should show up as statistically significant effects of the date of Brexit in appropriate regression relationships of UK variables on their determinants. Of course, the data has notoriously been highly volatile due to the major shocks just noted. This militates against finding significant Brexit effects, as common sense indicates. To anticipate our findings, we find some significant effects of disruption from Brexit but they are temporary and quite small, with slightly negative effects on GDP, exports and imports, and slightly positive effects on inflation and interest rates.

Identification of Brexit effects

To identify the short run effects of Brexit we have to use the dates when Brexit occurred- i.e. the 2016 referendum result and the end -2020 exit from the EU Single Market- as our variables of identification, on the assumption that what happened to economic events then reflected the effects of Brexit and only these. Even simply on UK data this is quite a demanding assumption as other shocks coincided with these events- notably Covid but also government policy actions on various fronts. However, it is the best identifying strategy we have.

Some studies (notably Springford, 2022) have used the differential between UK behaviour and the behaviour of a 'doppelganger' weighted set of 30-odd other countries as their dataset and assumed that changes in the differential from the date of Brexit in 2016 identify the effects of Brexit. However, this identifying assumption is hard to support because from this date all the shocks in the other 30-odd countries could also be contributing to the differential; though they did not have Brexit, they had all their own shocks, including from policy changes. Whereas it is possible to combine some 30 countries' data for a particular macro variable over the past into a weighted combination that closely mirrors past UK data, that is a statistical artefact produced by varying the weights to favour countries that over the past happened to behave like the UK. But from the Brexit date their relative behaviour will depend on their idiosyncratic shocks, which will be creating effects at the same time as Brexit in the UK. We cannot distinguish these from Brexit.

Thus to give Brexit the best chance of being identified we need to estimate UK data behaviour alone and apply the Brexit dates to that, to find the short run effects on the macro economy. We know that a short run macro model can be solved out in the form of a Vector Autoregression, a VAR, where each variable depends on its own and other variables' past. We estimate a VAR for the UK, representing whatever true model of the economy is driving it; within the VAR we find the effects of the Brexit date variables, 'dummy variables' that take the value 1 in all periods after Brexit but zero before. Because these effects can be identified, we can treat this VAR as 'structural', that is revealing the effects of structural shocks. We can then trace out these VAR effects of Brexit.

This follows. We show first charts of all the data; it is obvious from cursory inspection that all series are dominated by the Covid episode, which therefore needs to be controlled for in order to have any hope of isolating the Brexit effects. Next, we show the estimates for the Brexit dummies in the VAR system- Table 1. Starred values of coefficients indicate 95% significance. As we would expect the Brexit dummies have significant impact effects on all the variables included. We then trace out their joint effects as time goes by according to this VAR system- Figure 2. It can be seen that there are effects on all the variables but that they all steadily die out.

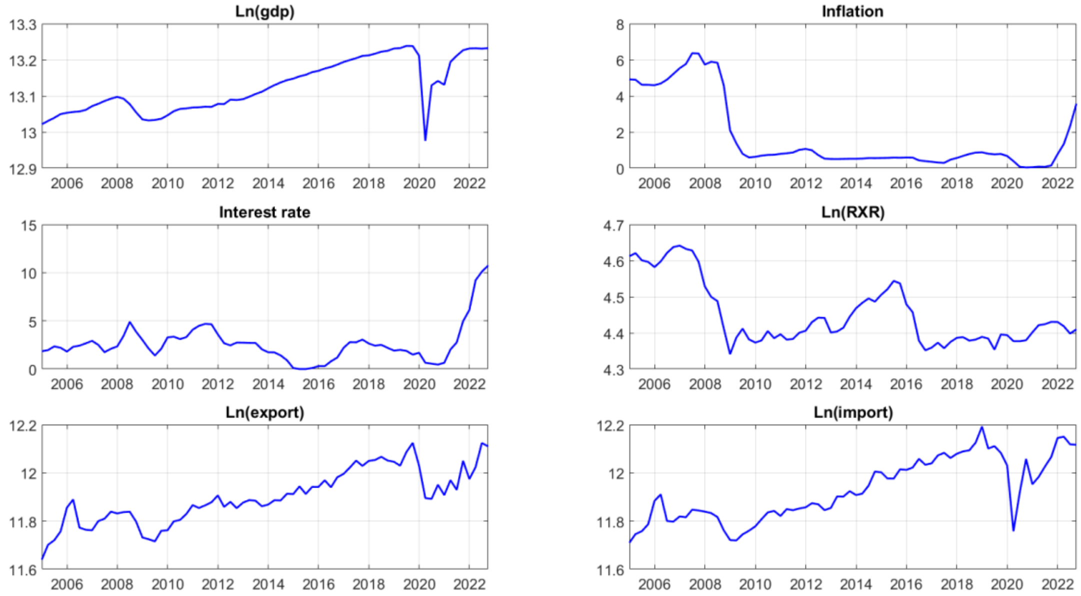

Figure 1: charts of the UK data series

VAR estimation results, 2005Q1 to 2023Q1

	GDP	Inflation	Interest rate	RXR	Export	Import
Lagged GDP	-0.463*	-3.451	-1.364	-0.151	-0.370	-0.699*
	(0.128)	(4.218)	(2.442)	(0.188)	(0.251)	(0.320)
Lagged Inflation	0.000	0.888*	0.149*	-0.001	0.008*	0.006
	(0.002)	(0.066)	(0.038)	(0.003)	(0.003)	(0.005)
Lagged Interest	0.011*	0.013	0.739*	-0.005	0.003	-0.003
rate	(0.003)	(0.098)	(0.057)	(0.004)	(0.006)	(0.007)
Lagged RXR	0.202	-1.998	5.351*	0.973*	0.129	0.048*
	(0.059)	(1.943)	(1.125)	(0.087)	(0.116)	(0.147)
Lagged Export	-0.107*	-2.548	0.804	0.105	0.132	-0.148
	(0.062)	(2.306)	(1.335)	(0.103)	(0.137)	(0.175)
Lagged Import	0.149*	4.946*	1.489	0.083	0.397*	0.588*
	(0.081)	(2.701)	(1.564)	(0.121)	(0.161)	(0.205)
Brexit referendum	0.045*	0.322	0.610*	-0.004	0.041*	0.082*
	(0.001)	(0.348)	(0.202)	(0.016)	(0.021)	(0.026)
Brexit departure	-0.083*	2.102*	-0.275	0.036	-0.084*	-0.116*
	(0.017)	(0.550)	(0.204)	(0.024)	(0.033)	(0.057)
COVID	-0.209*	-0.114	-0.109	0.018	-0.102*	-0.196*
	(0.018)	(0.592)	(0.236)	(0.026)	(0.035)	(0.045)
COVID recovery	-0.089*	-2.255*	0.422	-0.001	-0.075*	-0.116*
	(0.022)	(0.702)	(0.394)	(0.033)	0.004	(0.057)

Notes on VARX: Below each coefficient in parenthesis is shown the standard error; those that are significant at 5% are asterisked and used in the model simulation. The VARX includes a time trend and the log of potential output (derived from an HP filter) as the X set of trended variables.

Table 1: VAR estimation results on UK data, 2005 Q3 to 2023 Q3

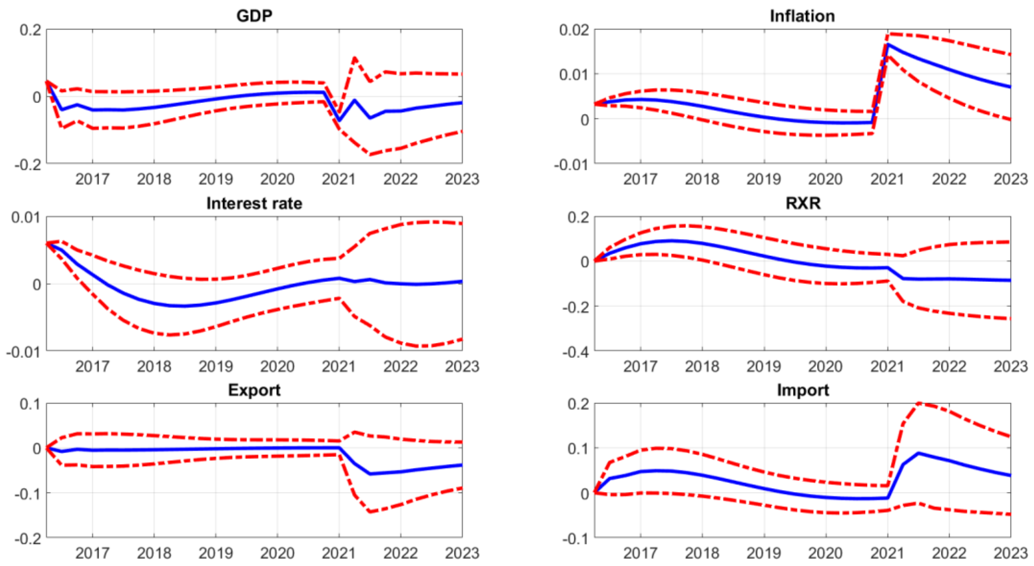

Figure 2: Effects of Brexit when inserted into the structural VAR (blue= estimated effect; red=95% confidence bands)

These joint effects come from the VAR.

As a check we can insert the Brexit effects into our underlying model of the UK (based on Zhu, 2017), to compare what that implies- Figure 3. It is fairly similar, as one would expect, since our underlying model is consistent with the VAR- we test the model by indirect inference, checking its match to a VAR of key variables, and it passes this test. This 'Cardiff model', which we use for forecasting purposes, is a New Keynesian model based on the one for the US in Le et al (2011). They fitted this closed economy model to US data, having found that the well-known Smets-Wouters (2007) model was rejected due to its excessive price/wage rigidity; their innovation was to add flexprice wage and price sectors to the model to create a 'hybrid' model with weights on both price-wage-setting and flexprice sectors; this model is then fitted to the data via indirect inference tests. For our model here of the UK, we adopt the same structure, simply adding open economy elements for trade and capital flows. Trade follows demand from households who switch between differentiated home and foreign products; household lending is arbitraged between home and foreign bonds, creating uncovered interest parity. The model's estimation period from 1975 to 2015 includes the period of Bretton Woods and various episodes of fixed-but-adjustable exchange rates, as well as several episodes of the zero lower bound, ZLB; in our work here we treat the Taylor Rule (Taylor, 1993) for monetary policy as operative throughout, capturing monetary behaviour in defence of quasi-fixed rates, with its simulated responses in the ZLB episodes representing 'shadow' policy effects equivalent to those of the Quantitative Easing measures (asset purchases financed by money printing) actually carried out then. The fact that the model with this monetary rule fits the data suggests it is a valid approximation. Details of the model and how we calculate the Brexit effects within it are given in Appendix A.

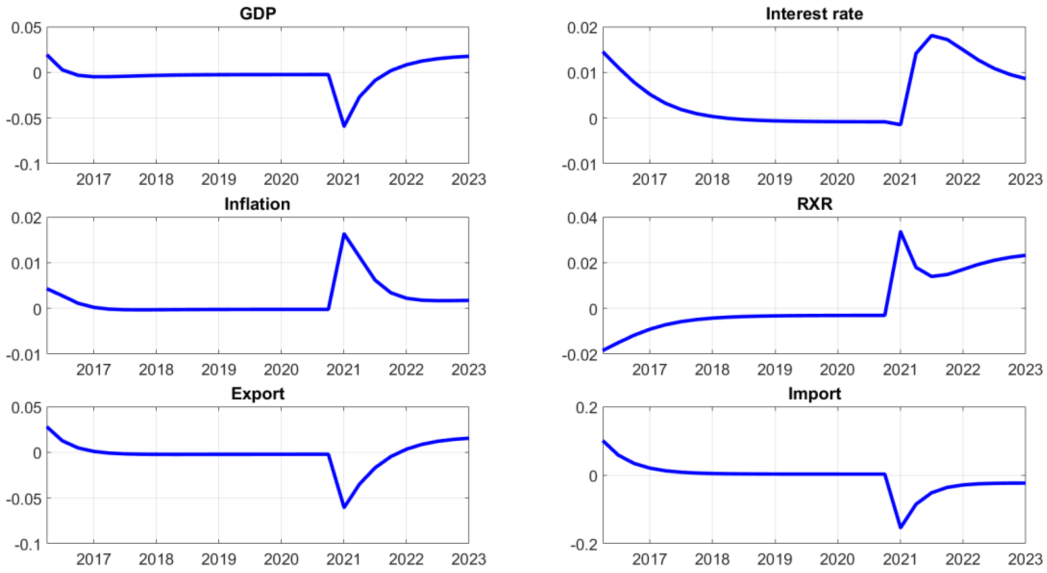

Figure 3: Effects of Brexit when inserted into DSGE model of UK

So in the short run what we find is that there are temporary effects on GDP, exports and imports (slightly negative), and on inflation and interest rates (slightly positive). What we see is a set of fairly minor temporary effects, consistent with modest disruption from introducing a border with the EU- a border due to be made barrier-free and seamless by the TCA.

Table 1 Variable definitions

Dependent Variable	Definition	Source
Export EU	Exports trade goods & services EU, SA	ONS
Export non-EU	Exports trade goods & services Non-EU, SA	ONS

Import EU	Imports trade goods & services EU, SA	ONS
Import non-EU	Imports trade goods & services Non. EU, SA	ONS
Independent Variable		
RXR	Effective real Exchange rate index	BoE
UK GDP	GDP, Chained Volume measure (CVM), SA	ONS
EU GDP	Millions of Chained 2010 Euros, Seasonally Adjusted	Eurostat
World import	Import trade in goods & services, constant price & PPPs	OECD
Brexit dummies	Referendum: 1from Q3 2016; departure 1 from Q1 2021-rest 0	-
COVID dummy	1 from Q2 2020 to Q4 2020, 0 otherwise	-
COVID recovery dummy	Q1 2021 = 1, 0 otherwise	-

The long run effects of Brexit

So far, we have just considered the short run effects of Brexit disruption due to the insertion of a new border between the UK and the EU; for this we have brought new modelling work to bear on the issue. However, the long run effects of Brexit are of much greater importance because both larger and permanent. Also, in our view they are to be seen as gains, not losses. In the following sections we survey the large modelling literature on these long term effects.

The economic gains for Brexit were envisaged to come from three directions and to accrue over the long term. First, there would be free trade with the rest of the world in place of high EU protection of agriculture and manufacturing. Second, there would be replacement of tightly prescriptive EU regulation in the tradition of Napoleonic law by pragmatic UK regulation in the tradition of the common law. Third, there would be control of immigration to ensure that those coming- from anywhere in the world- had the skills necessary to bring a net economic contribution to the UK, in place of an automatic right of entry to any EU citizen.

The key dispute over these gains has been over trade. They would come as set out above in the classical long run model of trade. Those opposed to Brexit have put forward an alternative 'gravity' model which assumes that the greater the distance in trade the less the effect of cost differences in shifting trade; we will see below that this model is close to the short run macro model we have used to calculate the short run effects. When this model is combined with the assumption that the border barrier between the UK and the EU is large and permanent, then this model predicts a loss from Brexit due to large UK-EU trade displacement. However, we will argue that this last assumption is false and that the gravity model is rejected by the data as a model of long run trade.

Free trade: there has been a largescale rollout of free trade agreements

Britain has just signed a highly significant trade agreement with nearly a dozen Asian countries- the Comprehensive and Progressive Agreement for Trade Partnership, the CPTPP; call it the Trans-Pacific Partnership, TPP, agreement for short. According to the Department of Trade's official assessment the TPP will add 0.08% to UK GDP in the long run, which has been derided by anti-Brexit opinion as negligible compared with the supposed loss of GDP due to lower EU trade, set at 4% of GDP by the UK's Office of Budget Responsibility.

These official estimates are based, as noted, on 'gravity' models which assume that trade effects of trade liberalisation fall off the higher the distance of a trade partner; and on the assumption that trade barriers with the EU must be raised by Brexit in spite of the Trade and Cooperation Agreement, TCA, with the EU whose aim, as noted above, is precisely to eliminate trade barriers between the UK and the EU.

Start with the second; it takes time first for negotiations on numerous details to be concluded, as the long discussions on implementing the NI protocol illustrate. It also takes time for people and businesses to adapt to the new border processes. But as the recent agreement on the Northern Ireland Protocol show, they eventually succeed. It is reasonable to assume that other details will similarly be sorted out over time; hence we should assume the TCA achieves its long run objective of removing trade barriers with the EU, in which case there will be no long run EU trade effects.

Now turn to the first issue of the gains from wider trade agreements, found to be minimal by the official model used. In our trade modelling work at Cardiff University we have repeatedly tested the 'gravity' model on different countries' data and found it to be widely rejected. The reason is that while of course 'gravity' (i.e. distance and size) does affect the extent of trade by itself, the effects of trade liberalisation and other changes over time have rather similar effects on all trade and they work by bringing down national prices into line with world competition; a model along these lines is generally consistent with the data. The 'gravity' model that says they have limited price effects and disproportionately affect nearer and larger trade partners is generally rejected by the data-see appendix B; Minford and Meenagh (2020, chapter 2) describes in some detail the wide variety of these gravity models applied to UK trade.

The TPP countries currently account for about 6% of our trade in goods- largely food and manufactures. But the key point totally missed in the official assessment is that our importers will now have a barrier-free source of these goods for them to access if they need to, which via competition will reduce our import prices on them to world levels. This in turn impacts on our consumer choices and our production structure. Eliminating the barriers to these import categories that we inherited from the EU- which are estimated to average about 20% - would according to our detailed model of UK trade and the economy increase UK GDP in the long run by around 6%- a big gain, very many times the official estimate- and lower consumer prices by 12%. This is the 'static' benefit, assuming trade does not grow, as of course it will, given that Asia is a fast growing part of the world economy.

A natural reaction to this estimate will be that, just as the official one was far too small, this one is extravagantly large. It is certainly true that it is based on a long term assessment, not the short term gravity models used by opponents of Brexit. It also assumes that in the long term there is free trade within this Pacific bloc which is the aim of the TPP; the initial agreement is hedged about with quota restrictions on the amount that can be freely traded but these should be eventually phased out as markets develop and confidence expands that they are not disrupting them; UK businesses will be incentivised to accept easier import access by the reciprocal access for their exports. Furthermore the TPP is due to expand as new members join; those interested include S Korea, Thailand, several Latin American economies and both Taiwan and China. The US could also return to being a member. As it expands the TPP will reinforce these competitive effects on the UK economy. The gravity models used to condemn Brexit are short term in focus, not much different from the ‘macroeconomic’ models we use for analysing the business cycle, and which we used above to calculate the short run effects of Brexit disruption. Hence they are inappropriate for calculating long run gains.

How this free trade agenda leads to a full Brexit with EU irrelevance

Because of the short term focus of the current Whitehall consensus gravity model, it is not well understood just what radical implications this free trade has for the UK’s future relations with the EU. As we have seen in the long term free trade implies equalisation of our home prices with world prices, which in turn means that we would export to the EU at these very same prices and would only import from the EU goods that were priced at the same competitive level.

This means that any threats by the EU to levy tariff or other trade barriers on UK goods in the course of any future negotiations on the TCA and any proposed new UK regulations, would be entirely empty. The reason is simple enough; UK export prices to the EU would be unaffected, as for example should they fall, UK goods would be diverted to other world markets at the full world price. Hence any EU trade barriers would simply raise the prices paid for UK goods by EU consumers. Should EU sales suffer as a result, then more goods would be sold elsewhere at world prices.

Similarly, if the UK were to raise barriers against EU imports in retaliation against any such EU barriers, it would not affect UK prices of these imports as they would have to compete with world imports to be sold at all. As a result EU sellers’ prices would be reduced. If as a result they supplied less imports, these would be replaced by imports from elsewhere.

It follows that the TCA itself would become irrelevant, dominated as UK trade with the EU would now be by the prices prevailing in the world at large. Furthermore, the EU would get most welfare from UK trade free of barriers as this would keep down the prices of UK goods to its consumers and keep up the prices of its UK exports to world prices. Hence we would expect that UK relations with the EU would default to barrier-free trade. As for UK regulations, the UK would be entirely free to set them as it suited it best, free of EU trade threats.

Two implications of the trade model used here are that the share of non-EU trade will trend downwards due to the falling trade barriers against the rest of the world, and the share of services exports will trend upwards due to the reduction in the relative prices of goods as their protection is dismantled. It can be seen from Figures 4 and 5 that both trends are visible in the current data.

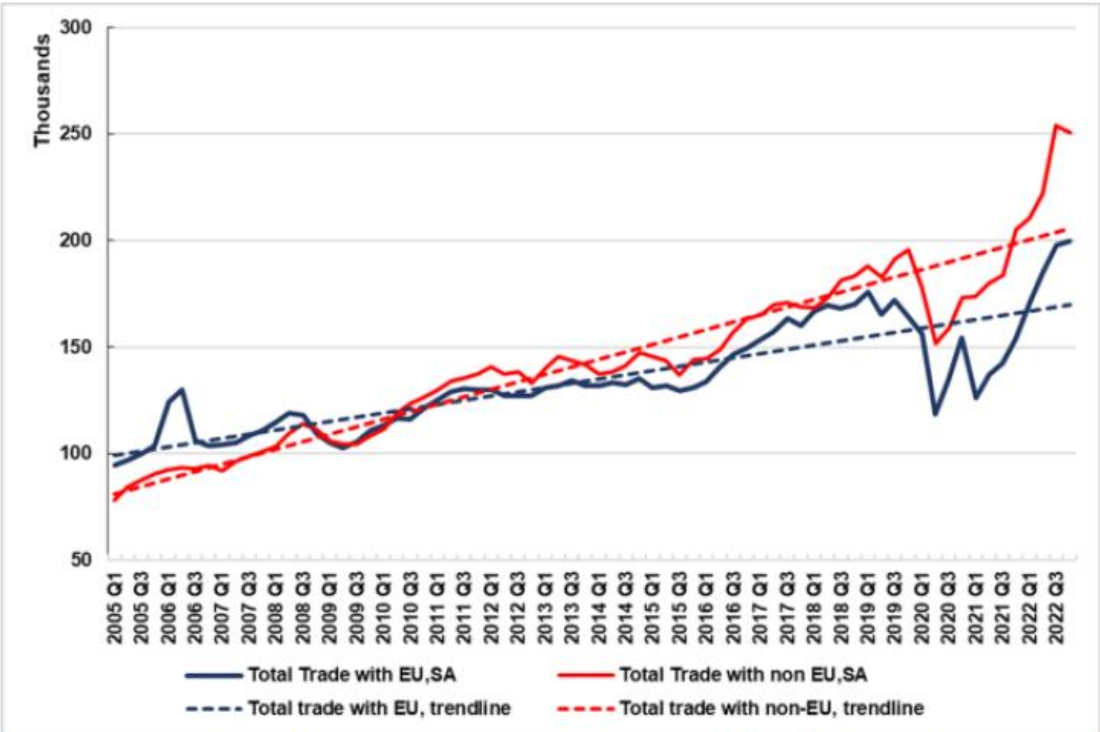

Figure 4: Trade (export+imports) with EU and rest of world, current prices, seasonally adjusted.

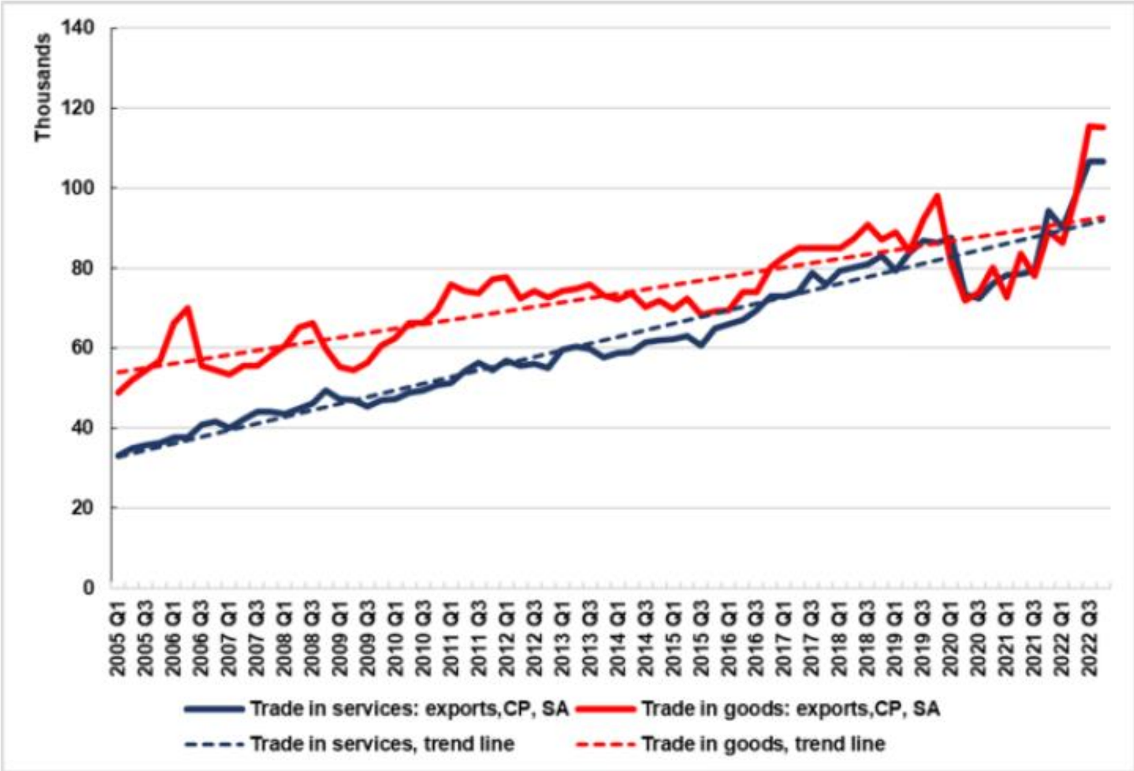

Figure 5: Export of services and exports of goods, current prices, Seasonally adjusted.

Progress in restoring UK-based regulation

It can be seen from this trade analysis that the UK will be unrestricted in its ability to restore UK-based regulation once free trade around the world is created. Meanwhile there has been progress on this front on the ground.

The current Bill going through Parliament mandates the sunsetting of all remaining EU regulations by the end of 2023; while this target date has now been abandoned as too ambitious, it is reasonable to assume the sunsetting process will be completed in the next year or so. Particular areas have already seen major change, such as for the City of London in the 'Edinburgh reforms'.

Existing regulations by now are also all the responsibility of UK regulators, under the direct control of Parliament. This will ensure that UK regulation is done by new UK processes supervised by UK law and regulators in consultation with UK industrial interests. The sunsetting intention forces these bodies to work urgently to find optimal UK replacements. One of the major objectives of Brexit is to replace the EU's intrusive precautionary principle with the pragmatic common law principles under which experimentation is permitted to enable vigorous innovation. As long as EU regulations are left in place by default, their replacement is delayed by bureaucratic inertia. As nature abhors a vacuum, so the abolition of remaining EU regulations should stimulate the necessary consultations to produce new UK-based regulation.

The gains from this change in regulation were estimated at 6% of GDP using the supply-side of the UK model- see Minford and Meenagh, 2020, chapter 3.

Immigration

Opponents of Brexit feared that it would lead to a sharp reduction in immigration, causing shortages of labour across an economy facing an ageing and eventually declining population. However, this was never the intention and net immigration has increased since Brexit, and opened up entry to the UK to countries all over the world. While the labour market has tightened, this has been caused by the loss of home labour supply due to Covid.

The gains from this liberalisation were estimated in Ashton, Mackinnon and Minford (2016) at 0.4% of average household disposable income. These consisted in stopping the inflow of unskilled labour with effects on the welfare of poorer households.

Conclusions

In this paper we have examined the model-based evidence on the effects of Brexit on the UK, both short term and long term. For the short term we have estimated a structural VAR identifying the Brexit effects via event dummies, then applying these estimates both to the VAR and our underlying DSGE model of the UK to find the resulting quantitative effects. We find that there are temporary effects on GDP, exports and imports (slightly negative), and on inflation and interest rates (slightly positive). What we see is a set of fairly minor temporary effects, consistent with modest disruption from introducing a border with the EU- a border due to be made barrier-free and seamless by the UK-EU Trade and Cooperation Agreement. There has been enormous turbulence in the past few years in all economies due to Covid and the Ukraine war, besides accompanying large fiscal and monetary policy fluctuations. Brexit is one policy shift among many shocks, and estimating its effect is fraught with uncertainty. Economic theory suggests it will have had a disruptive effect on EU trade in the short run as businesses adapt to a new border and the resulting new paperwork and related processes. But the TCA is designed to create a barrier-free and seamless border; so we should expect this effect to be dissipated steadily- including in the future as the TCA is streamlined by new talks- and not to be permanent. This is consistent with these findings from the data.

The long term effects of Brexit based on classical models of trade are much disputed by proponents of 'gravity' models of trade. We have surveyed the evidence for both types of model, implying the widespread rejection of gravity models on long term trade data, even if these models are useful in predicting business cycle facts, qua macro models- indeed the DSGE model used to estimate short run effects was similar. The classical trade models that are universally accepted on the long term trade data imply substantial gains from the free trade policies the UK has pursued since Brexit. Our supply-side models predict similarly large gains from the introduction of common law-based regulation replacing EU Napoleonic-law-based regulation, as also from the liberalisation of UK immigration law focused on worldwide access for skilled immigrants.

Thus the overall conclusion from this exploration of modelling Brexit effects on the UK is that while there has been some short term disruption due to the new UK-EU border; this should be temporary as the TCA eliminates trade barriers between the UK and the EU and free trade pushes UK trade towards world prices. Meanwhile the models that fit the data imply there should be substantial long term gains to the UK from free trade, regulatory reform and liberalised immigration.

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Appendix A: The Cardiff DSGE model of the UK

Indirect Inference estimation of the model

We assess the performance of the DSGE model by matching the behaviour of UK data covering the period from 1975Q1 to 2015Q4 at a quarterly frequency and evaluate the model's ability to capture the features and dynamics of three key variables: output, inflation, and interest rates during the time period-for an account of indirect inference and its methods of application, se Le et al (2016). The t statistics and p-value of the model are reported at the bottom of the following Table. The model using the calibration parameter values is strongly rejected by the Wald test, with a p-value of 0%. In contrast, the II estimated model has a p-value of 16%, comfortably passing the test at the 5% significance level.

Table Indirect Inference estimates and p-value of the DSGE model

Parameters	Description	Calibration	II estimation
Fixed parameters and steady state value			
β	Discount rate	0.998	0.998
δ	Capital depreciation rate	0.025	0.025
R_k^*	Return rate of capital	0.04	0.04
$\bar{\gamma}$	Quarterly output growth	0.55	0.55
$\bar{\pi}$	Quarterly inflation	1.29	1.29
$\frac{G}{Y}$	Government spending to GDP ratio	0.20	0.20
$\frac{C}{Y}$	Consumption to GDP ratio	0.58	0.58
$\frac{I}{Y}$	Investment to GDP ration	0.18	0.18
$\frac{EX}{Y}$	Export to GDP ratio	0.24	0.24
$\frac{IM}{Y}$	Import to GDP ratio	0.25	0.25
$\frac{C^e}{Y}$	Net worth to GDP ratio	0.008	0.008
e_p	Goods market curvature of the Kimball aggregator	10	10
e_w	Labour market curvature of the Kimball aggregator	10	10
θ	Survival rate of entrepreneurs	0.99	0.99
Households			
σ_c	Intertemporal elasticity of substitution	1.39	1.30

h	degree of External habit formation	0.70	0.57
σ_L	Frisch elasticity of labour supply	1.83	3.11
ξ_w	degree of wage stickiness	0.70	0.82
ι_w	Degree of wage indexation	0.58	0.48
ω^w	Proportion of sticky wages	0.40	0.38
Producers			
ξ_p	Degree of price stickiness	0.75	0.71
ι_p	Degree of price indexation	0.24	0.20
ψ	Elasticity of capital utilization	0.54	0.63
Φ	1+Share of fixed costs in production	1.50	1.75
φ	Steady state elasticity of investment adjustment cost	5.74	5.64
α	Share of capital in production	0.33	0.28
ω^r	Proportion of sticky prices	0.10	0.11
Taylor rule			
r_p	Response to inflation	2.50	2.68
ρ	Interest rate smoothing	0.60	0.56
r_y	Response to output	0.08	0.06
$r_{\Delta y}$	Response to output change	0.22	0.21
Financial frictions			
χ	Elasticity of the premium with respect to leverage	0.04	0.05
Variables in auxiliary model Y, π, R			
T-stats		3.68	1.01
P-Value		0.00	0.16

Brexit Effect Insertions from VAR estimations

We analyse the Brexit effect using VARX estimation through combinations of five individual structural shocks identified in the full DSGE model. These shocks encompass the Consumption preference shock, impacting GDP; the monetary shock, influencing interest rates; the price mark-up shock, affecting inflation; the export demand shock, influencing exports; the import demand shock, impacting imports; and the foreign interest rate shock, affecting the real exchange rate. For each shock, we first impose the estimated VARX coefficient for the Brexit referendum dummy as the predetermined value in the initial period (2016Q1). Next, we impose the estimated coefficient for the Brexit departure dummy as a second shock after 17 periods (2020Q2). By incorporating the individual effects together, we analyse the overall effect of Brexit on the DSGE model.

Log-linearized model list

Consumption Euler Equation

$$c_t = c_1 c_{t-1} + c_2 E_t c_{t+1} + c_3 (l_t - E_t l_{t+1}) - c_4 (r_t - E_t \pi_{t+1}) + eb_t$$

$$c_1 = \frac{\frac{h}{\gamma}}{1+\frac{h}{\gamma}} c_{t-1};\ c_2 = \frac{1}{1+\frac{h}{\gamma}};\ \ c_3 = \frac{(\sigma_c - 1)\left(\frac{W_*^h L_*}{C_*}\right)}{1+\frac{h}{\gamma}};\ \ c_4 = \left(\frac{1-\frac{h}{\gamma}}{1+\frac{h}{\gamma}\sigma_c}\right)$$

Investment Euler equation

$$i_t = \frac{1}{1+\beta\gamma^{(1-\sigma_c)}} \left[i_{t-1} + \beta\gamma^{(1-\sigma_c)} E_t i_{t+1} + \frac{1}{\gamma^2 \varphi} q q_t \right] + ei_t$$

Aggregate production function equation
$$y_t = \phi[\alpha k_t^s + (1-\alpha) l_t + ea_t]$$

Relationship between effectively rented capital and capital
$$k_t^s = k_{t-1} + z_t$$

Degree of capital utilization
$$z_t = \frac{1-\psi}{\psi}\ rk_t$$

Capital accumulation equation

$$k_t = \left(\frac{1-\delta}{\gamma}\right) k_{t-1} + \left(1 - \frac{1-\delta}{\gamma}\right) i_t + \left(1 - \frac{1-\delta}{\gamma}\right)\left(\left(1 + \beta\gamma^{(1-\sigma_c)}\right)\gamma^2\varphi\right) ei_t$$

Hybrid Keynesian Phillips curve equation

$$\pi_t^{NK} = \frac{\beta\gamma^{(1-\sigma_c)}}{1+\beta\gamma^{(1-\sigma_c)}\iota_p} E_t \pi_{t+1} + \frac{\iota_p}{1+\beta\gamma^{(1-\sigma_c)}\iota_p} \pi_{t-1} - \frac{1}{1+\beta\gamma^{(1-\sigma_c)}\iota_p} \left(\frac{\left(1-\beta\gamma^{(1-\sigma_c)}\xi_p\right)(1-\xi_p)}{\xi_p\left(1+(\Phi_p - 1)e_p\right)}\right) \Big(\alpha r_t^k + (1-\alpha) w_t - ea_t\Big) - ep_t$$

$$\pi_t^{NC} = mc_t = (1-\alpha) w_t + \alpha r_t^k - ea_t$$

$$\pi_t^{hybrid} = w^p \pi_t^{NK} + (1 - w^p)\pi_t^{NC}$$

Hybrid wage equation
$$w_t^{NK} = \frac{\beta\gamma^{(1-\sigma_c)}}{1+\beta\gamma^{(1-\sigma_c)}\iota_p} E_t w_{t+1} + \frac{1}{1+\beta\gamma^{(1-\sigma_c)}\iota_p} w_{t-1} + \frac{\beta\gamma^{(1-\sigma_c)}}{1+\beta\gamma^{(1-\sigma_c)}} E_t \pi_{t+1} - \frac{1+\beta\gamma^{(1-\sigma_c)}\iota_w}{1+\beta\gamma^{(1-\sigma_c)}} \pi_t - \frac{\iota_w}{1+\beta\gamma^{(1-\sigma_c)}} \pi_{t-1} - \frac{1}{1+\beta\gamma^{(1-\sigma_c)}} \left(\frac{\left(1-\beta\gamma^{(1-\sigma_c)}\xi_w\right)(1-\xi_w)}{\xi_w\left(1+(\Phi_p - 1)\epsilon_w\right)}\right) \left(w_t - \sigma_l l_t - \left(\frac{1}{1-\frac{h}{\gamma}}\right)\left(c_t - \frac{h}{\gamma} c_{t-1}\right) \right) + ew_t$$

$$w_t^{NC} = \sigma_l l_t - \left(\frac{1}{1-\frac{h}{\gamma}}\right)\left(c_t - \frac{h}{\gamma}c_{t-1}\right) - (\pi_t - E_{t-1}\pi_t) + ew_t^s$$

$$w_t^{hybrid} = w^w w_t^{NK} + (1-w^w)w_t^{NC}$$

Labour demand equation

$$l_t = -w_t + \left(1 + \frac{1-\psi}{\psi}\right)rk_t + k_{t-1}$$

Taylor rule

$$r_t = \rho r_{t-1} + (1-\rho)\left(r_p\pi_t + r_y y_t\right) + r_{\Delta y}(y_t - y_{t-1}) + er_t$$

External finance premium equation

$$E_t cy_{t+1} - (r_t - E_t\pi_{t+1}) = \chi(qq_t + k_t - nw_t) + epr_t$$

Arbitrage equation for the value of capital (Tobin's Q):

$$qq_t = \frac{1-\delta}{1-\delta+R^K}E_t q_{t+1} + \frac{R^K}{1-\delta+R^K}E_t rk_{t+1} - E_t cy_{t+1}$$

The evolution of entrepreneur's net worth

$$nw_t = \theta nw_{t-1} + \frac{K}{N}(cy_t - E_{t-1}cy_t) + E_{t-1}cy_t + enw_t$$

Real uncovered interest rate parity

$$q_t = E_t q_t + \left(r_t^f - E_t\pi_{t+1}^f\right) - (r_t - E_t\pi_{t+1})$$

Export demand equation

$$x_t = c_t^f + \frac{1}{\omega}\sigma^f q_t + ex_t$$

Import demand equation

$$m_t = c_t - \sigma q_t + em_t$$

The evolution of net foreign assets position

$$\hat{b}_t^f = \left(1 + r_t^f\right)\hat{b}_{t-1}^f + \frac{p_t^d}{q_t}\frac{x}{y}ex_t + \frac{p_t^d}{q_t}\frac{x}{y}\frac{1}{\omega}q_t - \frac{m}{y}m_t$$

Resource constraint

$$y_t = \frac{c}{y}c_t + \frac{i}{y}i_t + \frac{k}{y}R^K z_t + \frac{c^e}{y}c_t^e + \frac{x}{y}x_t - \frac{m}{y}m_t + eg_t$$

Stochastic process

Government spending shock

$eg_t = \rho_g eg_{t-1} + \sigma_g \eta_t^a + \eta_t^g$

Preference shock shock

$eb_t = \rho_b eb_{t-1} + \eta_t^b$

Productivity shock

$(ea_t - ea_{t-1}) = \rho_a (ea_t - ea_{t-1}) + \eta_t^a$

Investment-specific shock

$ei_t = \rho_i ei_{t-1} + \eta_t^i$

Monetary policy shock

$er_t = \rho_r er_{t-1} + \eta_t^r$

Price mark-up shock

$ep_t = \rho_p ep_{t-1} + \eta_t^p$

Wage mark-up shock

$ew_t = \rho_w ew_{t-1} + \eta_t^w$

Labour supply shock

$ew_t^s = \rho_w^s ew_{t-1}^s + \eta_t^{ws}$

External finance premium shock

$epr_t = \rho_{pr} epr_{t-1} + \eta_t^{pr}$

Net worth shock

$enw_t = \rho_{nw} enw_{t-1} + \eta_t^{nw}$

Export demand shock

$ex_t = \rho_x ex_{t-1} + \eta_t^x$

Import demand shock

$$em_t = \rho_m em_{t-1} + \eta_t^m$$

Exogenous foreign consumption process

$$c_t^f = \rho_c^f c_{t-1}^f + \eta_t^{cf}$$

Exogenous foreign interest rate process

$$r_t^f = \rho_r^f r_{t-1}^f + \eta_t^{rf}$$

Appendix B: How the gravity model fails in tests of its ability to mirror long term trade trends

Many followers of economic debate think that a good test of a theory is its ability to forecast future events. But it turns out that forecasting well is a bad test of a model; many poor models forecast well, and many good models forecast badly. Forecasts in other words have little to do with how well a model understands the underlying causal processes at work, which is what we care about. Models that are based on exploiting lagged indicators usually forcast better than good causal models, and all forecasts are upset by big shocks that are unforecastable, reducing forecasting ability all round and making forecast success largely a matter of luck. This criticism also applies to 'likelihood ratio' testing which is based on models' capacity to forecast past data accurately.

Instead a reliable way of testing models is to ask if they can mimic the behaviour of real world data. This behaviour is produced by the unknown true model, so the closer a model can get to producing similar behaviour, the greater its claim to be the true model. This test of a model is known as 'indirect inference' testing; in this method the data behaviour is described accurately by some past relationships found in the data, and the proposed causal model is simulated to see if it implies relationships close to this- and so is ‘indirectly’ similar rather than ‘directly’ forecasting data. In repeated ’Monte Carlo’ experiments using mocked-up data from supposed true models we have found that these indirect inference tests are extremely powerful in rejecting false models, whether of the macro economy or of trade.

In recent work at Cardiff we have asked whether a model of world trade including all the major countries or country blocs of policy interest- the US, the EU, China, the UK, and the rest of the world- can mimic these countries’ behaviour in trade and output. We have a ‘classical’ and a ‘gravity’ version of the model. The results are striking- as the Table below of the probabilities of each model for each country and the world as a whole show rather strikingly. What can be seen is that the gravity model probability falls in all cases below the 5% cut-off level (i.e. 0.05), while the Classical model generally has a probability well above this level. The only exception is the US whose individual facts are not well fitted by either model. Nevertheless the Classical model fits the world as a whole very well. It also fits UK trade facts particularly well. These results echo earlier results of tests of these models country by country- Chen et al, 2021.

Table 2: Test results of the full world global model

Country	P-values	
	Classical Model	Gravity Model
UK	0.2429	0.0412*
US	0.0337*	0.0078*
Euro Area	0.0936	0.0114*
CH	0.0829	0.0142*
World	0.3095	0.026*

Note: p-value with * indicates a rejection of the model at 5% significance level.

Source: Minford, P., Dong, X., Xu, Y. (2021)’ Testing competing world trade models against the facts of world trade’, Cardiff Economics working paper E 2021/20. http://carbsecon.com/wp/E2021_20.pdf

This testing failure of the gravity model applies strongly to UK trade in particular (as found some time ago in Minford and Xu, 2018- https://link.springer.com/article/10.1007/s11079-017-9470-z)

You might ask why so many economists adhere to gravity models in commenting on Brexit. The answer seems to be that these models do quite well in mimicing short term macro behaviour, in effect behaving like business cycle macro models, which frequently use the same gravity assumption that trade in different countries' goods compete imperfectly. But while this assumption works well for the short run, in the long run it breaks down as competition irons out differences between products. We know that in the short run Brexit is bound to cause disruption, but the whole point of Brexit, as we have seen, is to improve long run performance- in the process ironing out the EU trade disruption through the improving TCA.