Supply Stocktake (3/10)

Note title: **What are the prospects for UK productivity convergence with the US?**

STRUCTURAL ECONOMIC ANALYSIS DIVISION

Authors:

NOTE FOR RECORD

[1]

WHAT ARE THE PROSPECTS FOR UK PRODUCTIVITY CONVERGENCE WITH THE US?

Main message**:** *Based on an econometric analysis of relative TFP and productivity levels in the UK and the US, there appears to be room for stronger productivity growth in the UK over the next three years compared to the current forecast (F15). In the medium term, the current assumptions on trend productivity growth underlying the forecast are in line with the econometric analysis. However, these results are highly uncertain and on a fundamental level, depend on the UK economy being able to make progress on slow-moving long-term structural drivers of productivity, like investment, effective R&D spending and educational attainment. Furthermore, from an econometric perspective, long-term data suggests that even if there was a cointegrating relationship between productivity levels in the UK and the US before the financial crisis, this relationship has broken down in recent years.*

Background

The concept of productivity[2] catch-up is well established in macroeconomic literature[3], and there is ample evidence in long-run historical data for the tendency of both advanced and emerging economies to convergence to a "technological frontier" – typically the US. Convergence is generally thought to take place through convergence in total factor productivity (TFP), as catch-up economies adopt technologies from frontier economies. However, in recent years, and especially after the onset of the financial crisis, the ability of catch-up economies to resume historical convergence trends is very much an open question. This note examines the evidence for productivity catch-up potential in the UK, both from an econometric and structural perspective.

Levels of productivity and TFP

Long-term time series (available from Bergeaud et al. (2015)) show that UK productivity levels started catching up with the US in the 1960's after widening during the immediate post-war years (Chart 1). Between the two world wars and after WWII, the US benefited from not having human and physical destruction on its own soil as well as from more competitive product markets. The UK, along with other advanced economies started catching up with the US in the 1960's due, for example, to the diffusion of US technologies and a catch-up in education levels[4] (Bergeaud et al. (2015)). The productivity catch-up process continued until the beginning of the financial crisis in 2008, albeit it slowed down markedly during the ICT boom after the mid 1990's (see below). Since the onset of the crisis, productivity dynamics between the two countries have diverged. A similar story of the more recent history emerges by looking through a lens of a shorter up-to-date quarterly dataset (Chart 2).

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[1] With input from (ID).
[2] In this note, productivity is defined as output per hour.
[3] See, for example, Baumol (1986), Bernard and Jones (1996a), (1996b) and Cameron et al. (2005).
[4] Statistically, there was a large structural break in UK productivity catch-up with the US at this time, according to Bergeaud et al. (2015).

Chart 1
Annual UK and US labour productivity levels (in 2010 PPP USD volumes).

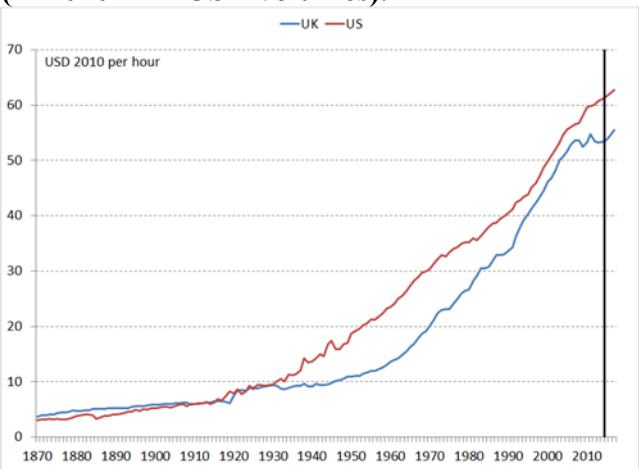
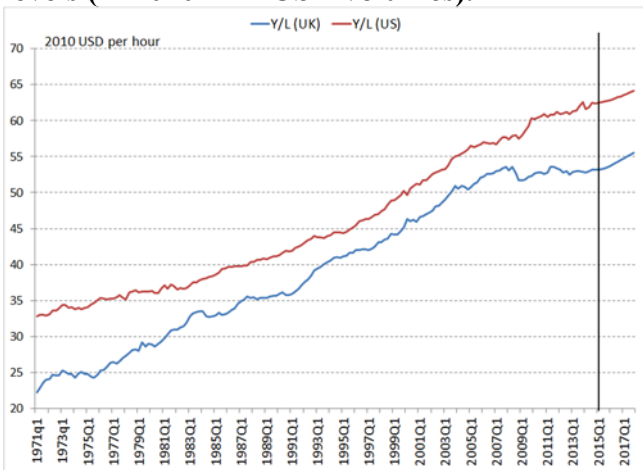


Chart 2
Quarterly UK and US labour productivity levels (in 2010 PPP USD volumes).



Assuming a traditional Cobb-Douglas production function and using the most recent quarterly data for the UK and the US on GDP and labour as well as capital inputs[5], relative TFP levels between the two countries can be calculated (Chart 3). The chart suggests that for TFP levels, the evidence of convergence is less conclusive than that for productivity. TFP growth appears to have been relatively similar in the two countries for most of the sample, before diverging during the crisis[6].

There have been significant fluctuations in relative productivity and TFP levels, and the UK catch-up with the US appears to have stalled well before the financial crisis (Chart 4). The dynamics from the late 1980's to the late 1990's are particularly volatile, and most probably reflect the effects of ICT. In line with previous literature (see, for example, Basu et al. (2003)), the data suggests that on the back of an IT investment boom in the late 1980's, relative UK productivity/TFP levels rose strongly in the early 1990's, and then fell in the late 1990's as the US exploited the general-purpose features of the ICT boom more efficiently.

The implied productivity and TFP levels of the latest forecast (F15) are also included in the previous charts[7]. The forecast implies a change in the post-crisis downward trend in the UK/US productivity and TFP levels (Chart 4), as the pick-up in UK productivity is projected to be significantly stronger than that in the US. Given that especially for TFP, there has been no clear upward trend in the relative productivity indicator since the late 1970's, the prospects for a sudden change in the trend appear debatable.

[5] For details on the data and methodological considerations, see Appendix A.
[6] Based on previous literature, TFP levels in the UK would be expected to have been lower than in the US, so this data is contentious. However, the results could be driven by recent data revisions and it should also be pointed out that particularly the TFP estimates are heavily dependent on the assumptions on capital stocks, labour share and exchange rate conversions (Appendix A). Different assumptions can lead to differences in TFP levels in particular, but the data used should nevertheless provide a useful basis for studying relative cross-country TFP dynamics.
[7] The implied projections for productivity and TFP take into account the F15 forecasts for GDP and labour input in both the UK and the US. Capital input is projected with the PIM method based on F15 investment forecasts, as detailed in Appendix A. For an update on ID view on productivity growth in the US,

Chart 3
UK and US TFP levels (in 2010 PPP USD volumes)

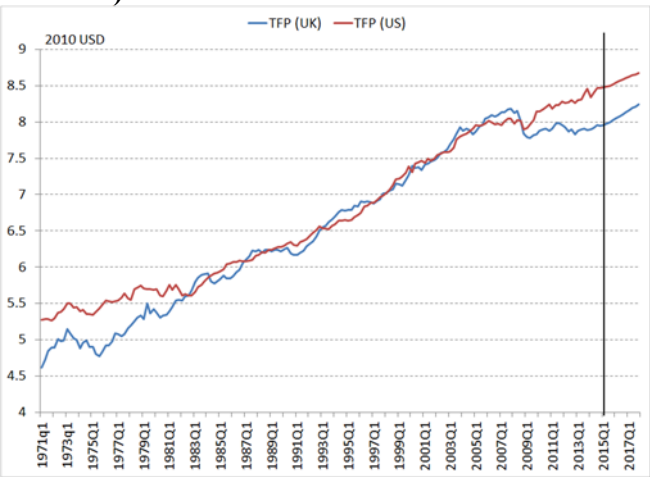
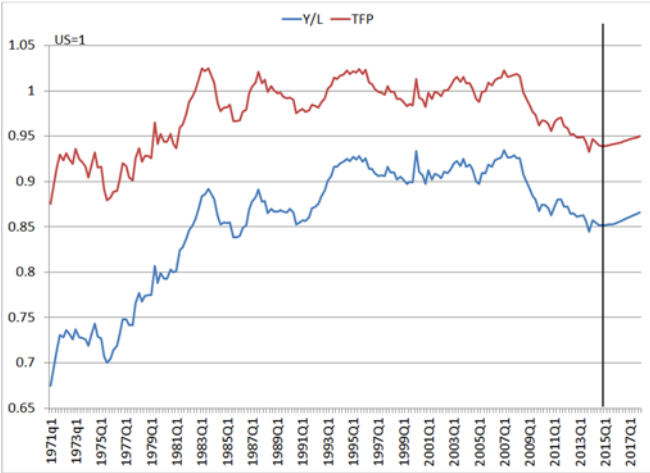


Chart 4
UK and US relative productivity/TFP levels



To shed light on the projected resumption of productivity convergence towards the US levels, some established econometric tools were applied to three different datasets;

1. Post-war annual productivity data (1945-2014) (available from the authors of Bergeaud et al. (2015), with updated GDP and labour hours data for the UK and the US);
2. Quarterly productivity data (1971q1-2014q4) (based on available data on GDP and labour hours for the UK and the US);
3. Quarterly TFP data (1971q1-2014q4) (based on capital stock estimates for the UK and the US provided by the authors of Bergeaud et al. (2015) until 2013, with Bank estimates of capital stock for 2014[8]).

To test for convergence between the UK and the US in an econometric sense, traditional cointegration tests[9] were applied to these datasets. The results suggest that when the whole sample, including the financial crisis period, is used, none of the tests can reject the null hypothesis of no cointegration. Excluding the crisis period (2008-2014), a cointegrating relationship is found for the longer annual productivity sample, but not for the quarterly samples. The change in the cointegration relationship is worth emphasising: we have seen such a large shock to the relative productivity levels during the financial crisis period that historically robust convergence trends have broken down.

While these results may seem surprising when looking at the trends in Charts 2 and 3, cointegrating relationships between trending series are generally not very common, and there is also some evidence for the lack of convergence in advanced economies in the literature (see Bernard and Durlauf (1995)). The cointegration results of the long annual productivity time series in the current note are broadly

[8] See Appendix A for details on the construction of the capital stock data. Also note that to allow for comparisons between the UK and the US, the UK capital stock data used is not directly comparable with the in-house capital stock estimates (with different assumptions on capital accumulation and depreciation) developed by However, the growth dynamics of the UK in-house measure and the measure used in the current note are broadly similar.

[9] See Appendix B for more details on cointegration tests, model specifications and estimation results.

consistent with the analysis presented in Bernard and Durlauf (1995); there is no evidence for the time series converging to the same level, but just to a common cointegrated linear stochastic trend.

As the analysis in this note is based on both productivity as well as TFP data, it is useful to analyse the contribution of TFP to productivity growth. Chart 5 compares the productivity growth in the UK versus the US over the crisis period, together with implied projections based on the latest forecast. As expected, the majority of the fluctuations in the relative growth rates is explained by changes in relative TFP growth. However, capital deepening also plays a role, especially towards the end of the forecast horizon. But overall, TFP dynamics can be expected to provide useful signals on productivity dynamics in the UK.

Econometric models of catch-up

Based on the results of the cointegration test above as well as evidence presented in previous literature, the UK TFP and productivity data was taken to the following two modelling frameworks:

1) A vector error-correction model applied to the annual productivity data from 1945 to 2007. This is justified based on the existence of a cointegrating relationship in the longer term annual data.

2) Given the lack of a general cointegrating relationship in the TFP data, a more specific error-correction single-equation approach is adopted for TFP growth. This approach is based on a model introduced by Bernard and Jones (1996a), which links TFP growth in a catch-up country (in this case, the UK) to the technological frontier country (the US)[10] as well as selected structural indicators relevant for TFP growth (see Cameron et al. (2005), Johansson et al. (2012)). The model is estimated in two different versions;

    a. one with quarterly data without exogenous variables, with a sample from 1971Q1 to 2014Q4;

    b. one with annual data including exogenous variables[11]. Due to data availability, this model can only be estimated for a sample from 1985 to 2010. Relevant indicators for some of the structural exogenous factors (in the form of UK levels relative to the US) are presented in Chart 6. The two variables included in the annual single-equation model (based on model diagnostics) are educational attainment and R&D spending (a proxy for innovation).

Armed with these three models, a scenario analysis comparing the latest productivity forecast (F15) to the forecasts implied by the models is carried out[12]. The results of this exercise are presented in Table 1. Based on model diagnostics and data issues, the quarterly model is the preferred model. This model

[10] For more details on the specification and estimation results, see Appendix B.

[11] The choice of data frequency is driven by the lack of quarterly data for the most relevant structural indicators.

[12] Three things are worth pointing out. 1) The model forecasts are conditional on F15 US productivity and TFP forecasts, which are relatively conservative compared to e.g. current Fed projections. However, the model forecasts are very robust to changes in the US TFP assumptions. 2) The end points of the estimation samples for the three models are different, which is unavoidable due to data issues and model specifications. Hence, the VECM assumes that the coefficients prevailing before the crisis would apply from 2015 onwards, while the quarterly model incorporates the data up until 2014Q4 for estimating the coefficients and then applies these coefficients from 2015Q1 onwards. 3) The structural indicators are assumed to remain at their current levels for the annual single-equation model.

would currently indicate a higher productivity growth profile in the near-term than the one in the latest projection. Of the annual models, the VECM is the preferred one, but obviously neither annual model is able to capture carryover effects from 2014 growth dynamics for 2015. Hence, the forecasts for 2015 look implausibly high. The forecasts from the annual models are also relatively high for 2016-17. For the VECM, this is due to the way the model – based on pre-crisis convergence relationships – expects UK productivity to start immediately converging towards the US levels[13].

Table 1 also includes forecasts for the year 2020 from the three models. Given the dynamics of the models, these can be seen as proxies for medium-term "potential" productivity growth implied by historical convergence relationships and model coefficient estimates. The results suggest that medium-term productivity growth is in the region of 2-2.5%, which is slightly higher than growth rates implied by F15 projections[14], but broadly in line with current long-term trend assumptions in COMPASS (2¼%). With regard to the historical forecasting ability of models 1 and 2a (2b is dropped from the analysis due to the short sample), the results are mixed; the quarterly model performs relatively poorly in comparison to a random walk assumption at longer horizons, although it does exhibit better performance at shorter horizons of 2-3 quarters, whereas the annual VECM performs relatively well at all horizons up to 5 years. Nevertheless, the longer-term model forecasts should be seen as estimates for potential rather than actual productivity dynamics.

Table 1: UK productivity growth scenarios

	Models			
	F15*	Annual VECM	Quarterly single eq.	Annual single eq.
2014	0.2	0.2	**0.2**	0.2
2015	0.6	2.5	**1.1**	2.0
2016	1.5	2.8	**1.8**	2.4
2017	1.8	2.7	**2.0**	2.5
2020	1.9	2.5	**2.0**	2.3

*Note: * assuming ONS data for 2014 and constant quarterly growth rates for key variables from 2018Q1 onwards.*

[13] According to the VECM, half of the approximately 15% gap in productivity levels between the US and the UK in 2014 is caught up in the next 5 years, whereas only about 20% is caught up according to the quarterly model.

[14] It is worth emphasising that this projection is based on extensions of 2018Q1 growth rates to 2012Q4 for GDP and labour hours for the UK and the US, and does not represent an MPC forecast.

Chart 5
UK minus US relative productivity growth

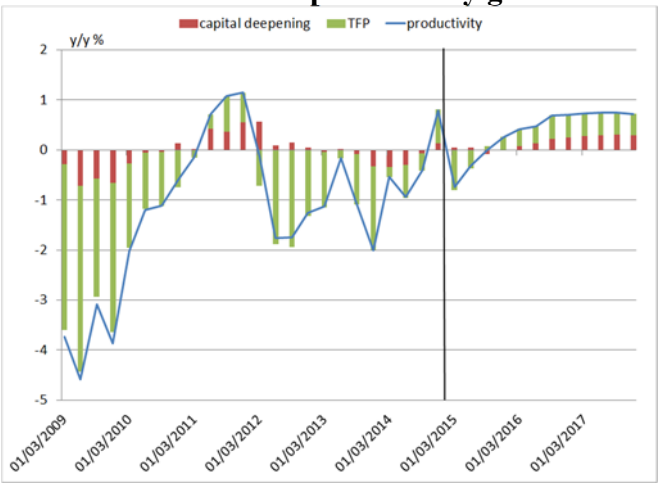
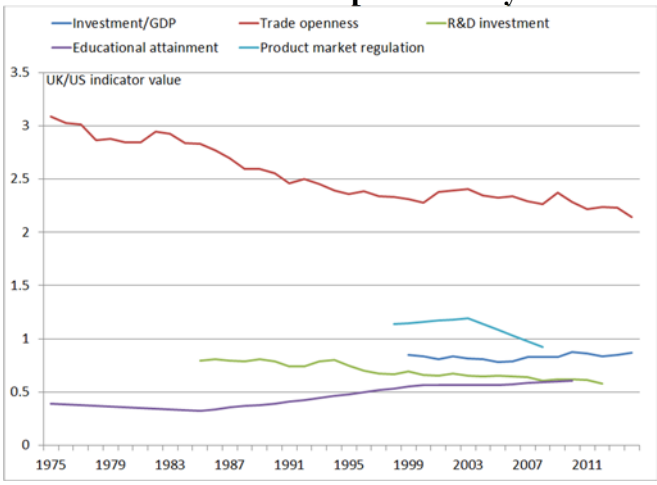


Chart 6
UK and US fundamental productivity drivers



Long-term structural drivers of productivity growth

Based on the previous section, there is some (mainly pre-crisis) econometric evidence pointing to potentially relatively rapid convergence dynamics of UK productivity towards the technological frontier represented by the US. However, it is far from obvious why this convergence should start after several years of diverging productivity dynamics between the two countries. Ultimately, the ability of the UK economy to catch up depends on being able to make progress on long-term fundamental factors driving long-term TFP growth. Some of these factors are presented in Chart 6. The two factors included in the annual TFP model above, educational attainment and R&D spending show diverging trends; the UK has been catching up on the educational attainment indicator, though it still remains well below the US levels, while R&D spending has declined steadily. For the other indicators, there are also diverging trends, but overall, the UK does not appear to compare particularly favourably to the US. There has not been any clear improvement in recent years, which would tend to cast doubt on the UK productivity convergence prospects, at least in the near term[15]. However, it needs to be kept in mind that fundamental factors typically move very slowly, and the model-based analysis above suggests that even slight improvements in the relative trends between the UK and the US could provide meaningful support to UK productivity growth prospects.

These conclusions on the long-term drivers of productivity are also corroborated by, for example, the recent OECD and European Commission economic surveys on the UK economy (European Commission (2015), OECD (2015)), which highlight the need for improvements in education, measures to reduce income inequality and poverty, further development of innovation and skills of the knowledge-based economy, strengthening investment, especially in infrastructure, and improving the financing of the economy as key measures to improving productivity in the UK.

[15] See also Weale (2014), which casts doubt on the ability of supply-side policies to address problems associated with productivity, as well as the ability of the UK economy to catch up with the US quicker than other advanced economies.

APPENDIX A – CONSTRUCTION AND SOURCES OF PRODUCTIVITY, TFP AND EXOGENOUS TIME SERIES

For the construction of the productivity and TFP time series, the conventional Cobb-Douglas production function of the following form is assumed:

$$Y_t = A_t L_t^{\alpha} K_t^{1-\alpha}$$

Where Y_t is real GDP, A_t is total factor productivity (TFP) (backed out as a residual), L_t is labour input (in hours), K_t is capital input (in volume terms) and α is labour share (all at time t). In this framework, labour productivity (Y_t/L_t) can be divided into contributions from TFP and capital deepening (K_t/L_t):

$$\frac{Y_t}{L_t} = A_t \left(\frac{K_t}{L_t}\right)^{1-\alpha}$$

The annual productivity data used in the note has been provided by the authors of Bergeaud et al. (2015) from 1870 to 2013, and this has been updated with the latest data for GDP and labour input for 2014.

The following data sources, assumptions and techniques are used to construct the relevant time series on a quarterly basis for the sample 1971Q1 to 2014Q4:

Y_t: quarterly national accounts data in chained 2010 volumes for both countries.

L_t: quarterly labour hours data from the OECD.

K_t: capital stock volume data (base year 2010) based on annual data provided by the authors of Bergeaud et al. (2015) from 1870 to 2013, intrapolated to quarterly frequency. For 2014 (and for the projection period 2015-17) capital stock data is updated with quarterly investment data with the Permanent Inventory Method (PIM), according to which capital is accumulated with investment flows, minus depreciation of the stock (a depreciation rate of 5% p.a. is assumed for both countries).

α: labour share is assumed to be constant 0.7 for both countries (widely used in literature and close to historical averages).

UK volume data is converted to USD 2010 levels using World Penn table PPP exchange rates, as in Bergeaud et al. (2015).

The sources of the exogenous time series used in the analysis are as follows:

Trade openness: (Exports+imports)/GDP, based on national accounts data

R&D investment: Annual OECD data on R&D expenditure/GDP shares

Educational attainment: Barro and Lee (2013) educational attainment statistics, using percentage of population with completed tertiary education. Data at five-year intervals, intrapolated to annual frequency.

Product market regulation indicator: OECD datasets in 1998, 2003 and 2008

Investment shares: Investment/GDP shares, based on national accounts data

APPENDIX B – ECONOMETRIC SPECIFICATIONS AND RESULTS

Both the longer annual sample of productivity (LP) (from 1945 to 2014) as well as the quarterly sample of both LP and TFP were first tested for a cointegrating relationship between the US and the UK data. This is based on the idea that to exhibit convergence, in an econometric sense, the time series should show some form of linear cointegration towards a common trend.

The so-called Johansen cointegration test was applied to the data[16]. This is based on the following error-correction presentation of a vector autoregressive (VAR) model of lag p:

$$\Delta y_t = C y_{t-1} + \sum_{i=1}^{p-1} G_i \Delta y_{t-i} + B x_t + e_t$$

where

$$C = \sum_{i=1}^{p} A_i - I$$

and

$$G_i = -\sum_{j=i+1}^{p} A_j$$

where y_t is a (2x1) vector of dependent variables (LP for the UK and the US or TFP for the UK and the US), C is a cointegrating matrix depending on matrices A_i of the reduced-form VAR model, G_i is the error-correction matrix, Bx_t is a vector of constants and e_t is an i.i.d. error term. Matrix C is further decomposed into (2xr) vectors a and b (C=ab'), where r is the cointegrating rank of matrix C. Johansen method estimates matrix C from an unrestricted VAR and tests whether r<k, indicating the number of cointegrating relationship exists.

Carrying out the Johansen test gives the following results (both trace and maximum eigenvalue tests are reported) for the three sets of data (long-term annual LP, short-term quarterly LP and short-term quarterly TFP):

[16] For more details on the Johansen test and cointegration, see e.g. Enders (1995).

	Annual LP	Quarterly LP	Quarterly TFP
Sample: from:	*1945*	*1971q1*	*1971q1*
to:	*2007*	*2007q4*	*2007q4*
Rank test (trace)			
None	0.0189 *	0.185	0.4357
At most one	0.133	0.1118	0.2606
Rank test (max eigenvalue)			
None	0.0266 *	0.2924	0.4872
At most one	0.133	0.1118	0.2606

* denotes rejection of the hypothesis at the 0.05 level

Lag length of 1 (based on lag length criteria) is used for all tests.

Test assumes a stochastic trend for all time series.

For the sample including the crisis period (2008-2014), none of the tests indicate that a cointegrating relationship exists. This is unsurprising, given the magnitude of the structural break in the data since 2008. For the pre-crisis sample, there is a cointegrating relationship (with one cointegrating vector) for the long-run annual sample, whereas no such relationship is found for the shorter quarterly samples. Hence, a vector error correction model (VECM) can be applied to the long annual LP dataset, but not to the other datasets.

A single-equation specification of the following form (based on Cameron et al. (2005)) is applied to the quarterly datasets for TFP:

$$\Delta lnA_t = b0 + b1 * \Delta lnAF_t + (1 - b2) * \ln\left(\frac{AF_{t-1}}{A_{t-1}}\right) + b4 * X_t + e_t$$

where A is the level of TFP in the ;UK, AF is the level of TFP in the technological frontier country (the US), X is a vector of exogenous variables, e is an i.i.d. error term and coefficients b0,…,b4 are parameters to be estimated. The choice of exogenous variables proxying for structural features and TFP growth potential is highly dependent on data availability. Annual data is available for indicators on trade openness, R&D investment and educational attainment. Different combinations of these exogenous variables are tested, with the results of the best model reported in the table below. This model includes R&D investment and educational attainment, but unfortunately, due to data availability, the sample size is small and the sample ends in 2010.

The estimation results of 1) the long-term annual VECM, 2) quarterly single-equation and 3) annual single-equation with explanatory variables are presented in the table below. In all three models, the coefficients are significant with expected signs. The diagnostics of models 1) and 2) indicate that the models are consistent, efficient and robust to changes in their specifications, while model 3) suffers from autocorrelation in the residuals, and due to the small size of the sample, is not as reliable as the other two models.

Regression results

Annual
VECM

Vector Error Correction Estimates
Sample: 1945 2007
Included observations: 63
Standard errors in ( ) & t-statistics in [ ]

Cointegrating Eq (C):		
US_LP(-1)	1	
UK_LP(-1)	-0.50041	
	-0.0914	
	[-5.47478]	
C equation constant	-20.3972	
Error Correction (G):	D(US_LP)	D(UK_LP)
CointEq1	0.028199	0.052323
	-0.01584	-0.01325
	[1.78003]	[3.94862]
D(US_LP(-1))	0.069023	0.018798
	-0.11893	-0.09948
	[0.58037]	[0.18897]
D(UK_LP(-1))	0.004043	0.160413
	-0.15277	-0.12779
	[0.02646]	[1.25533]
Constant	0.581765	0.575827
	-0.14033	-0.11738
	[4.14557]	[4.90554]
R-squared	0.102072	0.406959
Adj. R-squared	0.056415	0.376804
Sum sq. resids	13.05012	9.130591
S.E. equation	0.470307	0.39339
F-statistic	2.235614	13.49574
Log likelihood	-39.8015	-28.5507
Akaike AIC	1.390524	1.033357
Schwarz SC	1.526596	1.169429
Mean dependent	0.63	0.698889
S.D. dependent	0.484162	0.498323

Quarterly
single eq.

Dependent Variable: DLOG(TFP_UK)
Method: Least Squares
Sample (adjusted): 1971Q2 2014Q4
Included observations: 175

Variable	Coeff	Std. Error	t-Statistic	Prob.
C	0.001225	0.000873	1.403128	0.1624
DLOG(TFP_US)	0.326762	0.107312	3.044966	0.0027
LOG(TFP_US(-1)/TFP_UK(-1))	0.038533	0.017332	2.223233	0.0275

R-squared	0.069074	Mean dependent var	0.003105
Adjusted R-squared	0.058249	S.D. dependent var	0.00911
S.E. of regression	0.00884	Akaike info criterion	-6.60197
Sum squared resid	0.013442	Schwarz criterion	-6.54772
Log likelihood	580.6724	Hannan-Quinn criter.	-6.57996
F-statistic	6.381107	Durbin-Watson stat	1.899896
Prob(F-statistic)	0.002122		

Annual
single eq.

Dependent Variable: DLOG(TFP_UK)
Method: Least Squares
Sample: 1985 2010
Included observations: 26

Variable	Coeff	Std. Error	t-Statistic	Prob.
C	-0.25162	0.107386	-2.34312	0.029
DLOG(TFP_US)	0.569679	0.300897	1.893269	0.0722
LOG(TFP_US(-1)/TFP_UK(-1))	0.409996	0.180342	2.273442	0.0336
EDUC	0.166724	0.077154	2.160928	0.0424
RD	0.24385	0.099968	2.439286	0.0237

R-squared	0.44374	Mean dependent var	0.011667
Adjusted R-squared	0.337785	S.D. dependent var	0.01415
S.E. of regression	0.011515	Akaike info criterion	-5.91936
Sum squared resid	0.002784	Schwarz criterion	-5.67742
Log likelihood	81.95172	Hannan-Quinn criter.	-5.84969
F-statistic	4.188024	Durbin-Watson stat	1.40812
Prob(F-statistic)	0.011972		

REFERENCES

Barro, R. and J. Lee (2013), "A New Data Set of Educational Attainment in the World, 1950-2010", Journal of Development Economics, 104, pp.184-198.

Basu, S., J. Fernald, N. Oulton and S. Srinivasan (2003), "The Case of the Missing Productivity Growth, or Does Information Technology Explain Why Productivity Accelerated in the United States But Not in the United Kingdom?", NBER Macroeconomics Annual 2003, Vol. 18

Baumol, W. (1986), "Productivity Growth, Convergence, and Welfare: What the Long-Run Data Show", American Economic Review, 76(5), pp. 1072-85

Bergeaud A., G. Cette and R. Lecat (2015), "Productivity Trends in Advanced Countries between 1890 and 2012", Review of Income and Wealth (forthcoming)

Bernard, A. and S. Durlauf (1995), "Convergence in International Output", Journal of Applied Econometrics, 10, pp. 97-108

Bernard, A. and C. Jones (1996a), "Productivity Across Industries and Countries: Time Series Theory and Evidence", Review of Economics and Statistics, 78(1), pp. 135-46

Bernard, A. and C. Jones (1996b), "Comparing Apples to Oranges: Productivity, Convergence and Measurement Across Industries and Countries", American Economic Review, 86(5), pp. 1216-38

Cameron, G., J. Proudman and S. Redding (2005), "Technological Convergence, R&D, Trade and Productivity Growth", European Economic Review, 49, 775-807

Enders, W. (1995), "Applied Econometric Time Series", John Wiley & Sons

European Commission (2015), "Country Report United Kingdom 2015 including an In-Depth Review on the prevention and correction of macroeconomic imbalances", February 2015

Johansson, Å, Y. Guillemette, F. Murtin, D. Turner, G. Nicoletti, C. de la Maisonneuve, P. Bagnoli, G. Bousquet and F. Spinelli (2012), "Long-term Growth Scenarios", OECD Economics Department Working Papers No.1000

OECD (2015), "OECD Economic Surveys: United Kingdom 2015", February 2015

Weale, M. (2014), "The UK productivity puzzle: an international perspective", speech on 08/12/2014