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THE US-UK PRODUCTIVITY GAP IN THE TWENTIETH CENTURY: FROM TECHNOLOGY AND POPULATION PERSPECTIVES

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Abstract: Recent developments in endogenous growth models have enabled researchers to reconsider some key events such as the take-off of the United States in the twentieth century. This paper investigates the roles played by innovative activity and population growth on comparative total factor productivity (TFP) growth between the US and the UK in the period 1870–2009. The study finds that the comparative lead in the US TFP was significantly affected by innovative activity on the one hand and population growth on the other. While the first factor influenced TFP growth positively, the latter created a growth drag. Moreover, the findings strongly support the Schumpeterian growth hypothesis, where innovative activity has permanent growth effects in the long run.

Keywords: endogenous growth; productivity gap; technology; population

JEL classification: O30; O40

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1. Introduction

After the industrial revolutions and the Victorian era of prosperity, Britain was regarded as the *'workshop of the world'*, yet by the end of the nineteenth century the technological leadership had clearly passed to the United States. In terms of per capita income, the US was 75 percent of that of Britain in 1870 but by 1929 it had increased to 130 percent (Maddison, 1995; Romer, 1996). Moreover, during 1950 to 1970, US output per worker was 30 to 40 percent higher than other leading countries with almost the same gap in total factor productivity (Denison, 1967). This emergence of American leadership questions the rise of a positive productivity gap between the US and the UK, and how far the technological progress in the US sufficiently explains the relative productivity gap between the two economies. The comparison gets particularly interesting since Britain was the world's first industrialized nation and the US began as one of its colonies. Further it is yet to be examined whether any growth theory can sufficiently explain this technological leapfrogging.

The seminal work of Habakkuk (1962) argues that the key to American leadership from the early twentieth century was labor-saving technological progress. Since the late eighteenth century onwards, labor was substituted with capital by American entrepreneurs as a result of an inelastic labor supply. While Britain had a strongly entrenched social system, which provided few opportunities for the growth of new technologies and resulted in lower international demands for British exports, the US took over not only its large domestic market but also Britain's export market with its new and advanced manufactured goods. The US, which was initially an importer of technologies from Europe, was a rapid technological adopter and kept improving the old technologies to meet their own domestic demands (Rosenberg, 1981). A large domestic market along with abundant natural resources set the economy to take-off in the first half of the twentieth century (Abramovitz, 1986; Nelson and Wright, 1992; Abramovitz and David, 1996). Romer (1996) additionally suggests that resource abundance also interacted with scale to create an endogenous technological lead in manufacturing that continued into the twentieth century.

In contrast, Broadberry (1994; 1998) and Broadberry and Irwin (2006) argue that the US had a labor productivity lead over Britain in manufacturing from as early as the mid-nineteenth century, which it maintained consistently in the next century. US labor productivity growth was augmented by the transfer of resources from low productivity sectors such as agriculture to high productivity sectors such as services. Recent studies on endogenous growth have found some striking results about the roles of technological progress and population growth in explaining historical events. The unified theories of economic growth of Goodfriend and McDermott (1995), Galor and Weil (2000), Hansen and Prescott (2002) and Lucas (2009) all focus on innovations and population growth as the principal drivers of per capita income growth. Madsen *et al*. (2010a) find that, during the period of the First Industrial Revolution in Great Britain (1760–1850), population growth outpaced technological progress and resulted in slower growth. The productivity growth rate increased during the Second Industrial Revolution (1850–1913), with lower population growth and higher technological progress in the economy.

Nevertheless, if technological advances in the US were important in its takeover of its former leader Britain, the relative lead in innovative activity in the US should sufficiently explain the productivity gap between the two. In other words, the following function should hold:

$$\frac{A_{US_t}}{A_{UK_t}} = f\left(\frac{X_{US_t}}{X_{UK_t}}\right) \tag{1}$$

where A is the total factor productivity (TFP) and X is the research and development (R&D) input corresponding to the US and the UK, respectively. It is yet to be examined empirically whether technological advances in the US sufficiently explain the relative productivity growth between the two economies and whether it follows any particular theory of long-run growth. Establishing that would help us to pin down the role of endogenous technological progress on the one hand and population growth on the other in advancing an economy's take-off and forging ahead of others. In addition, unlike Madsen *et al*. (2010a), this study presents the theoretical justification for land being assumed as no longer a fixed factor of production and thus being allowed to vary over time.

The objectives of this paper are threefold: 1) to examine empirically whether the relative lead of technological progress in the US can sufficiently explain the productivity gap between the US and its former leader Britain; 2) to test empirically whether the productivity lead of the US follows any second-generation endogenous growth theories; and 3) to inspect the effect of population growth on the relative productivity growth of these two economies.

The paper is structured as follows: the next section graphically presents the historiography of the two economies from 1870 onwards. Section 3 details the theoretical basis and empirical methodology followed here. Section 4 discusses the empirical results and finally Section 5 concludes the analysis.

2. What Does the Long-Run Data Show?

This section provides a comparative analysis between the US and the UK in the period from 1870 to 2009. The period is dictated mainly by the availability of reliable technological measures for both economies. Although national economic data for these economies is available before this date, the reliability certainly increases after the 1870s, when per capita growth accelerated in most advanced countries, identifying the era as the modern period of economic growth (Maddison, 1995). Figure 1 below shows the comparative total factor productivity (TFP) and labor productivity (LP) of the US and the UK in the period 1870 to 2009. Comparative TFP is defined following Broadberry (1993). However, in contrast to Broadberry (1993), land is here incorporated as an additional factor of production, where comparative TFP is the geometric weighted average of comparative capital productivity, comparative land productivity and comparative labor productivity. This is expressed in eq. (2) below. If we do not include land separately as a factor of production, such as in Broadberry (1993), then eq. (2) reduces to eq. (3).

$$\frac{TFP^{US}}{TFP^{UK}}=\left(\frac{(Y/K)^{US}}{(Y/K)^{UK}}\right)^{\alpha}\left(\frac{(Y/T)^{US}}{(Y/T)^{UK}}\right)^{\beta}\left(\frac{(Y/L)^{US}}{(Y/L)^{UK}}\right)^{1-\alpha-\beta} \tag{2}$$

$$\frac{TFP^{US}}{TFP^{UK}}=\left(\frac{(Y/K)^{US}}{(Y/K)^{UK}}\right)^{\alpha}\left(\frac{(Y/L)^{US}}{(Y/L)^{UK}}\right)^{1-\alpha} \tag{3}$$

where Y is real output, T is land, L is employment and K is the real capital stock. Broadberry measures (1–α) in eq. (3) to be 0.77, which is the geometric mean of the US and the UK wage shares in net output in the year 1975, following van Ark (1990). The share of comparative land productivity (β) is measured here as share of agricultural income to total income. The value of β is set to 0.1, which is the geometric mean of the shares of agricultural income in total income in the US and the UK in the year 1975. The corresponding year of calculation of the share of comparative land productivity is chosen to be 1975 to keep the year of calculation constant among all comparative input productivities. Thus comparative labor productivity in eq. (2) is weighted by $(1-\alpha-\beta)$, the value of which is 0.67 after subtracting β from $1-\alpha$.

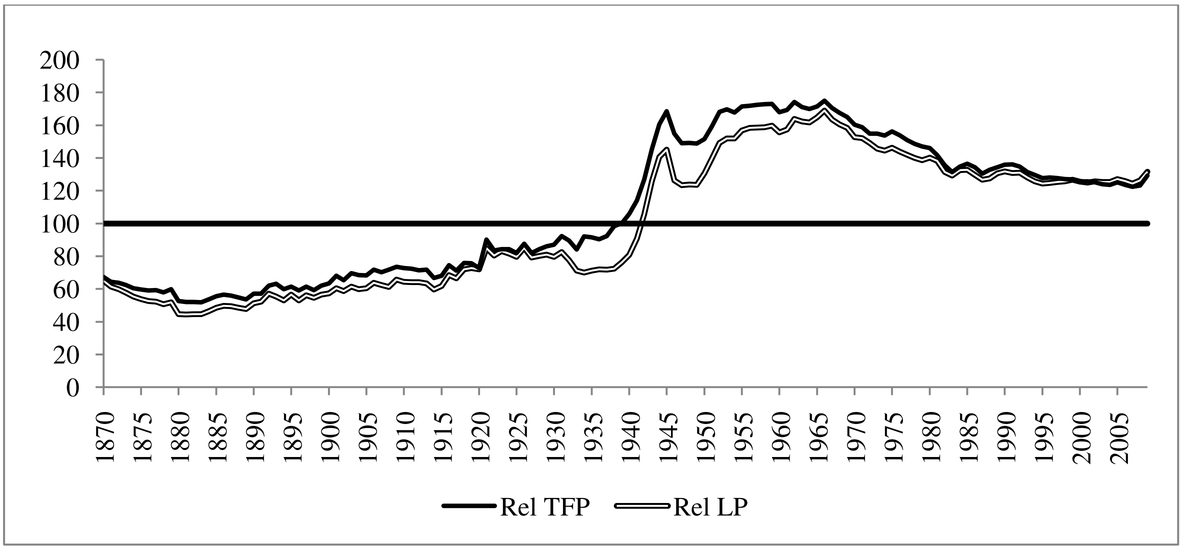
Eq. (2) can be further expressed in eq. (4) in terms of the ratio between comparative output levels and comparative total factor inputs (TFI):

$$\frac{TFP^{US}}{TFP^{UK}} = \frac{Y^{US} / Y^{UK}}{(K^{US} / K^{UK})^{\alpha} (T^{US} / T^{UK})^{\beta} (L^{US} / L^{UK})^{1-\alpha-\beta}} = \frac{Y^{US} / Y^{UK}}{TFI^{US} / TFI^{UK}} \tag{4}$$

The data sources are described in the appendix. In Figure 1, following eq. (4) the vertical axis measures the ratios of TFP and LP of the US and the UK, respectively. The UK is indexed to 100. In terms of catching up and convergence, when the UK is the productivity leader, the series are negative and falling. Furthermore, when the series are still negative but rising, it means that the US has started to catch up to the UK or that the gap between the two economies is reducing. However, if the series are positive and rising, it implies that the US has higher productivity growth than the UK.[1]

[1] 100 on the vertical axis imply that the productivities of the two economies have converged at that point in time.

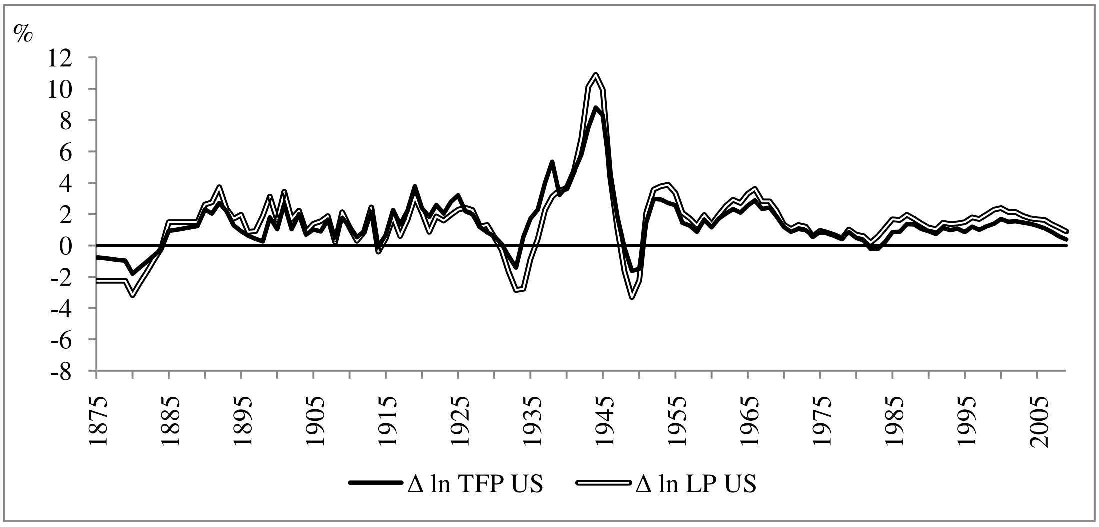
Figure 1: Comparative total factor productivity and labor productivity between the US and the UK, UK=100



Note: The comparative TFP is measured following eq. (3). Rel TFP and Rel LP correspond to comparative total factor productivity and labor productivity between the US and the UK. The period covers 1870–2009.

Before c.1890 the UK was the productivity leader when the trends of the comparative productivities are nonincreasing in Figure 1. In the last decade of the nineteenth century, labor productivity growth and TFP growth in the US began to increase at a faster rate than in Britain. This is demonstrated by the consistently increasing trend in the comparative TFP and LP in Figure 1 from 1890 to 1929. Productivity converged between the two economies in around 1940, with a steep increase after 1935. The period 1890–1929 can be termed as the early take-off period for the US, which led the foundation for America's dominance of the world economy in the twentieth century. Apart from the productivity slowdown during the Great Depression (1929–1930), the US maintained the lead over Britain. In the post-World War II era, due to technological catch-up by Europe, the comparative productivity lead of the US slowed in favor of the UK and finally, after 1970, the productivities converged in most OECD countries. The declining trends in Figure 1 show this convergence in the post-1970 period. However, the remarkable growth until 1970 made it possible for the US to keep a positive productivity lead even up to the present.

Figure 2: Total factor productivity growth and labor productivity growth in the US

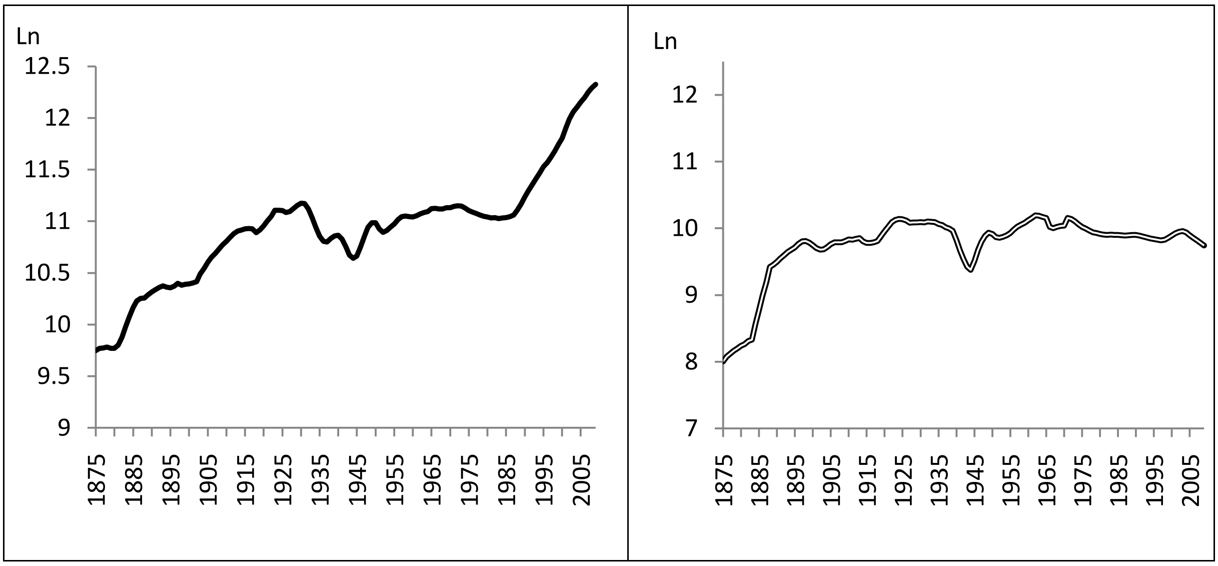


Note: The growth rates are based on five years' moving average of annual growth figures.

The total factor productivity and labor productivity growths of the US shown in Figure 2 confirm the findings from Figure 1. The productivity growths are positive in the period 1890–1929, marking the early take-off of the US economy. The high growth rates in the decade 1935–1945 in Figure 2 indicate the forging ahead from behind in Figure 1. The decline around 1945 marks World War II, after which the growth rates are again positive, except in the recessionary years of the 1980s.

To examine the trends of technology and population in the two economies in the twentieth century, Figures 3 and 4, respectively, plot the total patent applications to residents and population growth in the period 1870–2009. Figure 3(a) shows the trend for the US and Figure 3(b) shows the same for the UK. Comparing Figure 3(a) with 3(b) it is evident that the US had a positive increase in patent applications in the periods 1870–1929 and 1945–1970. Apparently, there has been a rising trend of technological progress in recent years in the US, which could have a positive effect on maintaining steady productivity growth rates in the post-1970 period. However, without proper empirical examination, it would be too early to comment on this. In contrast, Figure 3(b) clearly shows very little technological progress for the UK in the twentieth century. Total patent applications to UK residents show very little increasing trend after 1905.

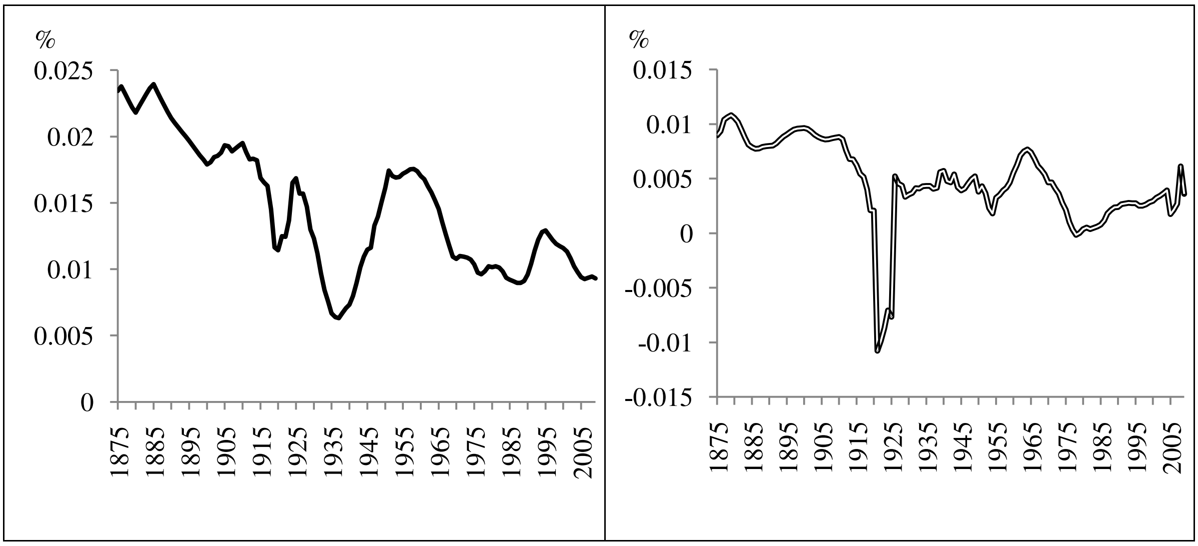
Figure 3: Patent applications to residents in the US and in the UK, 1870–2009



(a) Patent application to residents in the US (b) Patent application to residents in the UK

Note: The series are five years' moving average of annual figures.

Figure 4: Population growth in the US and in the UK, 1870–2009



(a) US population Growth, 1870–2009 (b) UK population Growth, 1870–2009

Note: The growth rates are based on five years' moving average of annual growth figures.

Finally, Figures 4(a) and Figure 4(b) compare the population growth in the two economies from 1870 onwards. While in Figure 4(a) the US population growth has a decreasing trend in the period 1870–1929, which covers the early take off period, there is no such evidence in the case of the UK in Figure 4(b). Apart from the sudden fall in the UK population growth around the 1920s, which follows the independence of Ireland in 1922, there are not many fluctuations in the first half of the twentieth century. In addition, the population growth rate in the US again decreased in the period 1950–1970, when the US was the world technological leader. Thus, combining the findings from Figures 1–4, it can be predicted that increasing productivity growth is more associated with falling population growth rates and higher technological progress for an economy such as the US. In addition, a downward trend in the US population growth suggests that higher productivity growth may create a downward pressure on fertility rates, and thus attain higher positive effects from technological progress. The arguments are similar to Galor and Weil (2000), who show that with higher technological progress, economy ultimately enters into a modern growth regime with reduced population growth and sustained income growth. Nevertheless, in the context of taking-off and forging ahead of an economy, empirical examination of the proposition is required before reaching any particular conclusion.

3. Theory and Empirical Methodology

Following Madsen *et al*. (2010a), however, relaxing the assumption of land to be a fixed factor of production, TFP growth is a race between population growth and technological progress. This can be shown following the simple homogenous Cobb–Douglas production function:

$$Y_t = A_t K_t^{\alpha(1-\beta_t)} T_t^{\beta_t} L_t^{(1-\alpha)(1-\beta_t)}, \tag{5}$$

where Y_t is real output, A_t is the knowledge stock, K_t is the capital stock, T_t is land, L_t is labor, $\alpha(1-\beta_t)$ is the share of income going to capital and β_t is the share of income going to land under the maintained assumption of perfect competition. The production function exhibits constant returns to scale in K_t, T_t and L_t and increasing returns to scale in A_t, K_t, T_t and L_t together.

In terms of per-worker output,

$$\left(\frac{Y}{L}\right)_t = A_t^{\frac{1}{1-\alpha(1-\beta_t)}} \left[\frac{K_t}{Y_t}\right]^{\frac{\alpha(1-\beta_t)}{1-\alpha(1-\beta_t)}} T_t^{\psi_t} L_t^{-\psi_t}, \tag{6}$$

$$or, \left(\frac{Y}{L}\right)_t = A_t^{\frac{1}{1-\alpha(1-\beta_t)}} \left[\frac{K_t}{Y_t}\right]^{\frac{\alpha(1-\beta_t)}{1-\alpha(1-\beta_t)}} \left(\frac{T}{L}\right)_t^{\psi_t}, \tag{6a}$$

where $\psi = \frac{\beta_t}{1-\alpha(1-\beta_t)}$. Labor productivity is expressed in terms of the K–Y ratio to filter out technology-induced capital deepening (Klenow and Rodriguez-Clare, 1997). Taking logs and differentiating eq. (6a) yields:

$$g_{y_t} = \frac{\psi_t}{\beta_t} g_{A_t} + \psi_t g_{t_t}, \tag{7}$$

$$or, \; g_{A_t} = \frac{\beta_t}{\psi_t} g_{y_t} - \beta_t g_{t_t}, \tag{7a}$$

where g_A is growth in TFP, g_y is labor productivity growth, and g_t is growth in land per unit of labor. Eq. (7a) shows the indirect effect of higher population growth on TFP growth. Since it is reasonable to believe that over time the growth rate of the population is significantly higher than the growth rate of available land, increase in population will trigger lower availability of land per unit of labor (T_t/L_t). The higher the rate of population growth, the higher will be the negative growth rate of land per unit of labor. Thus, increase in the growth rate of lower availability of land per unit of labor affects TFP growth rate negatively in the long run due to higher population growth rate. After per capita income passes the Malthusian straitjacket, higher productivity growth and education would induce parents to choose higher quality over quantity and thus lower the fertility rates (Galor and Wel, 2000). Consequently, it generates lower pressure from population growth on productivity growth with higher technological progress.

The role of capital for growth is suppressed in eqs (7) and (7a) under the assumption that the economy is on a balanced growth path in which the K–Y ratio is constant. Capital deepening cannot act as an independent growth factor since it is driven entirely by technological progress along the balanced growth path.[2]

Recent theories of endogenous growth models, particularly the semi-endogenous growth models developed by Jones (1995), Kortum (1997) and Segerstrom (1998) and Schumpeterian growth models developed by Aghion and Howitt (1998), Howitt (1999) and Peretto and Smulders (2002) have been tested widely in the context of modern and historical growth experience of economies.

[2] See Madsen *et al*. (2010a) for why productivity growth triggers capital deepening.

While empirically the Schumpeterian models have gained wide support from various researchers for modern and historical time periods, the semi-endogenous growth models have garnered almost no support in any of the occurrences (Ha and Howitt, 2007; Madsen, 2008; Ang *et al*., 2010; Madsen *et al*., 2010a; Madsen *et al*., 2010b). However, it is yet to be examined whether any of these theories well explain one of the significant episodes in the twentieth century – the US take-off and its forging ahead of its former leader, Britain. The key difference between these two theories can be explained by a simple ideas-production equation as follows:

$$g_A = \frac{\dot{A}}{A} = \lambda \left(\frac{X}{Q}\right)^{\sigma} A^{\phi-1},$$

$$Q_t \propto L^{\kappa} \text{ in steady state, } 0 < \sigma \leq 1 \qquad (8)$$

where σ is the duplication parameter (zero if all innovations are duplications and 1 if there are no duplicating innovations), ϕ is returns to scale in knowledge, κ is the coefficient of product proliferation, λ is the research productivity parameter, Q is a measure of product variety, L is employment or population and X is R&D inputs for semi-endogenous growth models or the productivity-adjusted R&D inputs for Schumpeterian growth models. The productivity adjustment in Schumpeterian models recognizes that there is a tendency for decreasing returns to R&D due to increasing complexity of innovations (Ha and Howitt, 2007). Semi-endogenous growth theory assumes that $\phi < 1$, $\sigma > 0$ and $\kappa = 0$ while Schumpeterian models assume that $\phi = 1$, $\sigma > 0$ and $\kappa = 1$.

Combining the justifications behind the negative effect of higher population growth rate on TFP growth rate in eq. (7a) and the predictions of the second-generation endogenous growth models in eq. (8) yields the following stochastic model for technology-driven productivity growth analysis in the US take-off phenomenon:

$$\Delta\, ln\, A_t^{rel} = a_0 + a_1\, ln \left(\frac{X}{Q}\right)_{t-1}^{rel} + a_2 \Delta\, ln\, X_{t-1}^{rel} + a_3 \Delta\, ln\, POP_{t-1}^{rel} + a_4 \Delta\, ln\, TO_t^{rel} +$$

$$a_5\, ln\, UNC_t^{rel} + a_6 \Delta\, ln\, FD_t^{rel} + a_7 \Delta\, ln\, LE_t^{rel} + \varepsilon_{1_t} \qquad (9)$$

$$\Delta\, ln\, A_t^{rel} = b_0 + b_1\, ln \left(\frac{X}{Q}\right)_{t-1}^{US} + b_2 \Delta\, ln\, X_{t-1}^{US} + b_3 \Delta\, ln\, POP_{t-1}^{US} + b_4 \Delta\, ln\, TO_t^{US} +$$

$$b_5\, ln\, UNC_t^{US} + b_6 \Delta\, ln\, FD_t^{US} + b_7 \Delta\, ln\, LE_t^{US} + \varepsilon_{2_t} \qquad (10)$$

$$\Delta\, lnA_t^{i} = c_0 + c_1\, ln \left(\frac{X}{Q}\right)_{t-1}^{i} + c_2 \Delta\, ln\, X_{t-1}^{i} + c_3 \Delta\, ln\, POP_{t-1}^{i} + c_4 \Delta\, ln\, TO_t^{i} + c_5\, ln\, UNC_t^{i} +$$

$$c_6 \Delta\, ln\, FD_t^{i} + c_7 \Delta\, ln\, LE_t^{i} + \varepsilon_{3_t} \qquad (11)$$

where A_t is TFP, POP_t is population, TO_t is trade openness, UNC_t is macroeconomic uncertainty, FD_t is financial deepening, LE_t is life expectancy at birth and ε is the stochastic error term. The period of estimation is 1870–2009. The growth models are estimated in three different parts. In the first step, all variables, both independent and dependent, are expressed in terms of the ratio between the US and the UK. Eq. (9) shows the regression model expressed in relative terms. The idea is that if any variable, such as technological progress, is responsible for the US take-off by advancing its productivity growth, the relative gap in innovative activity should also sufficiently explain the relative gap in productivities between the US and the UK. Once the results turn out to be significant, in the second step, the same regression model is run, keeping the growth of relative TFPs as the dependent variable, however, all independent variables now correspond to the US only. This is expressed in eq. (10). Findings from the second step regressions will confirm whether advancements in the US economy are responsible for creating the positive gap in productivities between the two economies. Finally, in the third step, eq. (11) is run, which corresponds to separate TFP growth estimations in each individual country. In eq. (11), i = *US, UK*. The results will confirm the roles of innovative activity and population growth in each country's productivity growth in the new century.

Here, the first two independent variables correspond to the measure of research intensity following the Schumpeterian growth models and the technological growth following the semi-endogenous growth models, respectively. X_t is measured by the number of patent applications by domestic residents; Q_t is measured by the labor force; TO_t is measured as the sum of exports and imports over GDP; UNC_t is measured by the five-year standard deviation of the annual growth of the consumer price index; FD_t is measured as the ratio of money stock over GDP; and LE is life expectancy at birth. Eqs (9), (10) and (11) are estimated in five-year nonoverlapping intervals to overcome cyclical influences and the erratic movements in the data on annual frequencies.

The growth in X and POP and the level of research intensity (X/Q) are lagged one period since it cannot be ruled out that innovative activity is driven partly by growth to the extent that activities leading to innovations are more affordable during upturns than downturns. Patent applications are the only currently available historical data for measuring innovative activity. Although past studies have argued for and against patent applications as an indicator of innovative activity, the measure is very common in the literature to capture innovations and technological progress (see Sullivan, 1989; 1990; Oxley and Greasley, 1998; Greasley and Oxley, 2007; Madsen, 2008; Ang *et al*., 2010; Madsen *et al*., 2010a; Banerjee, 2011).[3] An additional advantage of using patents as an indicator of innovative activity is that informal R&D is often patented (see Madsen, 2008).

While the indicators of technological progress and population growth are the key explanatory variables in eqs (9) (10) and (11), trade openness, macroeconomic uncertainty, the ratio of money to income and life expectancy are included in the regressions as control variables. The choice of control variables is dictated according to their importance in growth theory and also on availability of data. Several theoretical and empirical studies suggest that trade barriers inhibit productivity (Vamvakidis, 2002; Lucas, 2007; Madsen, 2009). Trade openness is not an ideal proxy for openness. However, better data on openness, such as tariffs and nontariff trade barriers, are not available for the earlier periods. The variable $(M/Y)_t$ is a proxy for financial deepening. Financial deepening influences income positively because it eases the access to credit, which in turn facilitates more efficient use of resources (e.g., Rousseau and Sylla, 2005; Ang and McKibbin, 2007; Ang, 2008). Inflation variability

[3] While Boehm and Silberston (1967) and Caballero and Jaffe (1993) argued against patents as an indicator of innovative activity, positive arguments can be found in the studies of Sullivan (1989), Griliches (1990) and Madsen (2007).

as a proxy for macroeconomic uncertainty is a drag on the economy because it is often associated with fiscal mismanagement, wars, and crop failures. Finally, productivity growth is often assumed to be a positive function of life expectancy because the incentives to invest in the future are positively correlated with the number of years in which an individual is expected to be productive (Cervellati and Sunde, 2005). Since a long life often goes hand-in-hand with a healthy life, an individual that is expected to live longer is likely to be more productive during their adult years. The next section discusses the empirical results.

4. Empirical Results

The first part of the regression results are presented in Table 1, which estimates the relative TFP growth in the period 1870–2009. Considering eq. (9), all independent variables in this stage are measured in relative terms. The results will capture the effects of relative movements of the factors in the two economies on their relative TFP growth. Implications from the two growth theories are simultaneously tested here.

The first independent variable ($ln\ X/Q$) refers to the level of research intensity following Schumpeterian growth models and the second variable ($\Delta\ ln\ X$) corresponds to the growth of innovative activity following semi-endogenous growth models. Six different regression models are run at each stage. The first model captures the effect of innovative activity corresponding to the two growth models and the effect of population growth. Thereafter, in each model an additional control variable is added following eq. (9). It should be noted here that although the first three independent variables in each regression equation look like they have been lagged for only one year; since the series are in five-year nonoverlapping period, the data take five-year intervals in every one period lagged. However, increasing further the number of lags in each variable will lose vital information significantly.

Table 1: Estimates of relative TFP growth: (eq. (9))

	(1)	(2)	(3)	(4)	(5)	(6)
$ln\left(\frac{X}{Q}\right)^{rel}_{t-1}$	0.02***	0.01***	0.01***	0.01***	0.02***	0.01***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\Delta\ ln\,X^{rel}_{t-1}$	0.10	0.11	0.09	0.07	0.14	0.17
	(0.49)	(0.30)	(0.36)	(0.51)	(0.25)	(0.22)
$\Delta\ ln\,POP^{rel}_{t-1}$	–0.01***	–0.01***	–0.01***	–0.01***	–0.01***	–0.01***
	(0.01)	(0.00)	(0.00)	(0.01)	(0.01)	(0.00)
$\Delta\ ln\,TO^{rel}_{t}$		–0.12**				–0.23***
		(0.05)				(0.00)
$ln\,UNC^{rel}_{t}$			–0.01**			–0.01***
			(0.02)			(0.00)
$\Delta\ ln\,FD^{rel}_{t}$				–0.10		–0.09
				(0.14)		(0.11)
$\Delta\ ln\,LE^{rel}_{t}$					1.11*	1.62***
					(0.06)	(0.00)

Note: The regression is estimated using five-year nonoverlapping series in the period 1870–2009. The dependent variable is $\Delta\ ln\,A^{rel}_{t}$. The Newey–West procedure is used to obtain heteroskedasticity and autocorrelation-consistent standard errors. An intercept is included but not reported. *p*-values are reported in brackets. *, ** and *** denote significance at 10%, 5% and 1%, respectively.

Irrespective of the choice of control variables, estimates in Table 1 show that relative levels of research intensity had consistently positive effects on relative TFP growth from 1870 onwards. While innovative activity in the US, following Schumpeterian models, well explains the TFP growth, there is no support in favor of the semi-endogenous growth model, where the coefficients are consistently insignificant. Relative population growth is negative and significant. The finding validates the prediction of the theory presented in the previous section. Further, in the choice of control variables, relative macroeconomic uncertainty had negative effects and relative life expectancy had positive effects on growth of relative TFPs. The results are consistent with the predictions of these variables in growth estimations. However, other control variables, such as financial deepening and trade openness, turned out to be either insignificant or showing the wrong sign. Nevertheless, the coefficients of research intensity and population growth remained consistent across different models.

Table 2: Estimates of relative TFP growth: contributions from the US (eq. (10))

	(1)	(2)	(3)	(4)	(5)	(6)
$ln\left(\frac{X}{Q}\right)_{t-1}^{US}$	0.17***	0.14**	0.18**	0.17**	0.17***	0.16***
	(0.01)	(0.03)	(0.02)	(0.03)	(0.00)	(0.00)
$\Delta\ ln\,X_{t-1}^{US}$	–0.12***	–0.10***	–0.14	–0.12	–0.09***	–0.10***
	(0.01)	(0.00)	(0.14)	(0.17)	(0.00)	(0.00)
$\Delta\ ln\,POP_{t-1}^{US}$	–1.92*	–1.82**	–1.74*	–2.18*	–1.77***	–1.25***
	(0.09)	(0.02)	(0.10)	(0.07)	(0.00)	(0.00)
$\Delta\ ln\,TO_{t}^{US}$		–0.18**				–0.12***
		(0.02)				(0.00)
$ln\,UNC_{t}^{US}$			–0.01**			–0.01***
			(0.03)			(0.00)
$\Delta\ ln\,FD_{t}^{US}$				0.14		–0.16
				(0.31)		(0.23)
$\Delta\ ln\,LE_{t}^{US}$					1.36***	1.14***
					(0.00)	(0.00)

Note: The regression is estimated using five-year nonoverlapping series in the period 1870–2009. The dependent variable is $\Delta\ ln\,A_t^{rel}$. The Newey–West procedure is used to obtain heteroskedasticity and autocorrelation-consistent standard errors. An intercept is included but not reported. *p*-values are reported in brackets. *, ** and *** denote significance at 10%, 5% and 1%, respectively.

Subsequently, Table 2 shows the estimation results of regression models following eq. (10). In this step of the empirical estimates, the contributions of factors such as innovative activity and population growth in the US economy are examined in advancing the comparative productivity growth of the two economies. It is believed that if gaps between factors in the two economies are significant in explaining comparative productivity growth, which is again profoundly dependent on the fact that growth in the US was higher than in the UK in the twentieth century, then factors from the US economy should also be significant in explaining the comparative TFP growth.

The estimation results in Tables 2 are very much consistent with the findings in Table 1. Research intensity, following the Schumpeterian model, is positive and significant in advancing the positive growth in comparative TFPs between the two economies in the period 1870–2009. At the same time no support is obtained in favor of the semi-endogenous growth theory. Contributions from higher population growth are negative and significant. The results are consistent with the inclusion of different control variables. The phenomenon confirms the effect on TFP growth due to lower availability of land per unit of labor, when land is a significant factor of production. Coefficients of the control variables show no significant difference from the findings in Table 1. While macroeconomic uncertainty was negative and significant, life expectancy was positive and significant in explaining relative TFP growth.

Finally, in step three of the empirical estimates, TFP growth is estimated for each individual country separately. Following eq. (11), while Table 3 provides the estimates for the US economy, Table 4 presents the same for the UK economy. Here, TFP growth in each country is estimated in the period 1870–2009, with the factors corresponding to that particular economy only. Consequently, estimates from the third stage of the regressions will offer some robustness check of results in addition to our findings in the previous two stages of empirical estimations.

Table 3: The estimates of US TFP growth (eq. (11))

	(1)	(2)	(3)	(4)	(5)	(6)
$ln\left(\frac{X}{Q}\right)_{t-1}^{US}$	0.11^{***}	0.09^{***}	0.12^{***}	0.10^{***}	0.11^{***}	0.11^{***}
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\Delta\ ln\,X_{t-1}^{US}$	$–0.03^{**}$	$–0.03^{**}$	$–0.06^{**}$	$–0.03^{*}$	–0.02	$–0.04^{***}$
	(0.05)	(0.03)	(0.02)	(0.06)	(0.63)	(0.00)
$\Delta\ ln\,POP_{t-1}^{US}$	$–2.03^{***}$	$–1.98^{***}$	$–1.83^{***}$	$–2.19^{***}$	$–1.92^{***}$	$–1.33^{***}$
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\Delta\ ln\,TO_{t}^{US}$		–0.07				$–0.05^{***}$
		(0.15)				(0.00)
$ln\,UNC_{t}^{US}$			$–0.01^{***}$			$–0.01^{***}$
			(0.00)			(0.00)
$\Delta\ ln\,FD_{t}^{US}$				0.08		–0.19
				(0.28)		(0.18)
$\Delta\ ln\,LE_{t}^{US}$					0.95^{**}	0.79^{***}
					(0.04)	(0.00)

Note: The regression is estimated using five-year nonoverlapping series in the period 1870–2009. The dependent variable is $\Delta\ ln\,A_t^{US}$. The Newey–West procedure is used to obtain heteroskedasticity and autocorrelation-consistent standard errors. An intercept is included but not reported. *p*-values are reported in brackets. *, ** and *** denote significance at 10%, 5% and 1%, respectively.

Interestingly, the parameter estimates in Table 3 are very consistent with the findings in the previous two tables, showing that the US indeed has experienced positive and significant technological progress in the twentieth century, which helped it leapfrog its former leader, Britain. While research intensity, following Schumpeterian growth models, was found to be positive and significant in advancing US productivity growth, no support was obtained for semi-endogenous growth models. The results are consistent with the findings of Ha and Howitt (2007), who found that trends in productivity and R&D in the US after the 1950s follow Schumpeterian models and not semi-endogenous growth models. However, this study goes further back in time and explains the growth process of the US take-off around the turn of the century. The magnitudes of the coefficients of the key variables and also the control variables are very much consistent across regression models and stages in Tables 2 and 3, respectively. This confirms our prediction that the factors responsible for US productivity growth can also successfully explain the relative gap between the productivities in the two countries.

Table 4: The estimates of UK TFP growth (eq. (11))

	(1)	(2)	(3)	(4)	(5)	(6)
$ln\left(\frac{X}{Q}\right)_{t-1}^{UK}$	–0.02 (0.17)	–0.02 (0.17)	–0.02 (0.14)	–0.03 (0.12)	–0.02 (0.14)	–0.01 (0.22)
$\Delta\ ln\,X_{t-1}^{UK}$	0.04 (0.19)	0.04 (0.20)	0.04 (0.20)	0.04 (0.13)	0.04 (0.13)	0.05 (0.11)
$\Delta\ ln\,POP_{t-1}^{UK}$	–1.37** (0.02)	–1.37** (0.02)	–1.40*** (0.01)	–1.69*** (0.00)	–1.17** (0.02)	–1.42*** (0.01)
$\Delta\ ln\,TO_{t}^{UK}$		0.01 (0.84)				0.09 (0.02)
$ln\,UNC_{t}^{UK}$			0.01 (0.80)			–0.01 (0.81)
$\Delta\ ln\,FD_{t}^{UK}$				–0.08* (0.06)		–0.04 (0.36)
$\Delta\ ln\,LE_{t}^{UK}$					–0.55** (0.02)	–0.42** (0.04)

Note: The regression is estimated using five-year nonoverlapping series in the period 1870–2009. The dependent variable is $\Delta\ ln\,A_t^{US}$. A dummy variable is included in the regression to capture the sudden fall of the British population growth rate due to Irish independence in 1922. The Newey–West procedure is used to obtain heteroskedasticity and autocorrelation-consistent standard errors. An intercept is included but not reported. *p*-values are reported in brackets. *, ** and *** denote significance at 10%, 5% and 1%, respectively.

While innovative activity from the US economy successfully explains the growth in their TFP, no significant result is obtained in the case of the UK. In Table 4, research intensity and growth in innovations are shown to be insignificant, offering support neither for Schumpeterian growth models nor for semi-endogenous growth models. However, coefficients of population growth are consistently negative and significant across all six regressions models.[4] This clearly indicates that population growth drag is still evident in the UK. Moreover, in the absence of technological progress, TFP growth will certainly fall in the long run with higher population growth. Thus, the estimation results confirm that one of the major factors that led to the British economic downfall in the twentieth century is lower degree of innovative activities than the US.

5. Conclusion

While the event at the center of America's success in leapfrogging its former leader Britain has received wide recognition from various researchers, little attention has been paid to examining empirically the roles played by innovative activity and population. This paper revisits the issue of comparative total factor productivity growth between the US and the UK in the period 1870–2009 and highlights some new facts on the importance of innovative activity and population growth in the creation of new economic leaders over time. In doing so, it also tests formally the two second-generation endogenous growth models, namely, Schumpeterian and semi-endogenous growth models.

The paper reconciles the theoretical and empirical findings with the historical facts very well. The graphical analysis presented in section 2 predicts that from 1870 onwards, and particularly after the 1890s, the US had higher innovative activity and lower population growth than the UK. Following Madsen *et al*. (2010a), the theoretical model in section 3 shows how TFP growth is a race between technological progress and population growth, when land is a factor of production. At the same time the sufficient conditions of holding the second-generation endogenous growth models are explained here. After examining the predictions carefully, the empirical results in section 5 support the US productivity lead over the UK in the twentieth century. The empirical tests are conducted in three steps. First, comparative factors are regressed on comparative TFP to see whether the US lead in innovative activity is properly reflected. Second, the contributions of the US in the productivity lead are examined by running regressions of factors from the US on comparative productivity growth.

[4] Annual data of British population show a sudden big drop c.1922, which is due to the independence of Ireland. Following Madsen *et al*. (2010), a dummy variable was added to the regression equation corresponding to this sudden fall of population.

Last, TFP growth is estimated in each individual country to capture country-specific characteristics. In all cases, the results support positive contributions from innovative activity in the US.

The results have important implications for catching up and convergence hypotheses and also for the future growth prospects of the US and the UK. The paper finds research intensity significantly influences productivity growth in the US in the post-1870 period. In each case, while innovative activity influences TFP growth positively, higher population growth affects it negatively. The findings also support the claims of Galor and Weil (2000). With higher technological progress, the US entered the modern growth regime, with reduced pressure from population growth and sustained income growth. In the post-Malthusian regime, higher productivity growth induces lower fertility rates thereafter. In contrast, no support of positive innovative activity is found in the UK in the same period. Moreover, the growth structure follows Schumpeterian growth models and not semi-endogenous growth models. The results are robust across the inclusion of different control variables. With less technological progress and positive population growth, Britain lost the race and transferred the leadership to the US in the new century. Thus, to become globally competitive, the quality of products needs to be improved continuously and this requires a skilled labor force and significant investment in R&D.

In addition, findings from this study show that economies with strong agricultural backgrounds but which lag behind the technological leaders should invest more on research and development and control the growth rate of population in the long run. Innovative activity in an economy is a significant driver of growth and plays a vital role for countries at take-off stages. The results are broadly consistent with the findings from some recent studies conducted on developing and developed economies (Ang *et al*., 2010; Madsen *et al*., 2010a; Madsen *et al*., 2010b; Ang and Madsen, 2011; Banerjee, 2011). Another empirical challenge would be to break down the present analysis on a sectoral basis and test in which sector innovations played a greater role in the US. A series of comparative sectoral analyses by Broadberry in recent times suggests that the US overtook its former leader Britain following the transfer of resources from low productive sectors such as agriculture to high productive sectors such as services. The manufacturing lead in the US has been present since the mid-nineteenth century (Broadberry 1993; 1998; Broadberry and Ghosal, 2005; Broadberry and Irwin, 2006). It would be interesting to examine whether investment in research and development happened more in the service sector, which helped the US economy to take off. However, this requires data on innovative activity for each individual sector for the two economies that goes back at least to the nineteenth century.

Data Sources

GDP: Real GDP is obtained from the following sources. *US*: 1870–1928: Kendrick (1961), p. 298; and 1929–2009: '*US Bureau of Economic Analysis (BEA)*' online database – http://www.bea.gov/. *UK*: 1870–1969: Mitchell (1988), pp. 845–847; and 1970–2009: OECD online database – www.oecd-ilibrary.org. In each case, the later series is spliced with the earlier series to get a complete database on an annual basis for the period 1870–2009.

The sources for nominal GDP are: *US*: 1870–1928: '*Historical Statistics of the United States, Millennial Edition*' (Vol. 3), edited by Carter *et al*. (2006), p. 23; 1929–2009: NIPA series from '*US Bureau of Economic Analysis (BEA)*' online database – http://www.bea.gov/. *UK*: 1870–1947: Mitchell (1988) and Feinstein (1972); 1948–2009: National Statistics Online (NSO): http://www.statistics.gov.uk/default.asp.

Labor: *US*: 1870–1955: '*Historical Statistics of the United States, Millennial Edition*' (Vol. 2), edited by Carter *et al*. (2006), pp. 77–82; and 1956–2009: OECD online database – www.oecd-ilibrary.org. *UK*: 1870–1955: from Mitchell (1988), p. 104; and 1956–2009: OECD online database – www.oecd-ilibrary.org.

Labor Hours: *US*: 1870–1949: '*Historical Statistics of the United States, Millennial Edition*' (Vol. 2), edited by Carter *et al*. (2006), p. 301; and 1950–2008: OECD online database – www.oecd-ilibrary.org. *UK*: 1870–1913: Huberman (2004); 1914–1969: Mitchell (1988), p. 147; and 1970–2008: OECD online database – www.oecd-ilibrary.org.

Land: *US*: 1870–1960: '*Historical Statistics of the United States, Millennial Edition*' (Vol. 4), edited by Carter *et al*. (2006), pp. 39–43; and 1961–2009: online database of the 'Food and Agricultural Organization (FAO)': http://faostat.fao.org/default.aspx. *UK*: 1870–1960: Mitchell (1988); and 1961–2008: online database of the 'Food and Agricultural Organization (FAO)': http://faostat.fao.org/default.aspx. The later series is spliced with the earlier series to get a complete database on an annual basis for the period 1870–2009 for each economy.

Capital: To calculate capital stock from the investment series, the perpetual inventory method is used, where 3% and 8% depreciation rates are taken for nonresidential structures and equipment and machinery, respectively.

US: real capital stock in nonresidential structures and equipment and machinery for 1870–1947 is from Kendrick (1961); and investment in nonresidential structures and equipment and machinery for 1948–2009 is from the NIPA series of 'US Bureau of Economic Analysis (BEA)' online database – http://www.bea.gov/. *UK*: Capital stock is measured as net capital stock at constant prices. For the period 1882–1948: Feinstein (1972); and for 1949–2009: National Statistics Online (NSO): http://www.statistics.gov.uk/default.asp.

Population: For both the *US* and the *UK*, 1870–1955 is obtained from the dataset compiled by Angus Maddison, available online at http://www.ggdc.net/MADDISON/oriindex.htm. 1956–2009 is obtained from the OECD statistical database www.oecd-ilibrary.org.

Patent applications: *US*: 1870–1882: 'total patent applications' are from Schmookler (1966), Table A4, p. 228; *UK*: 1870–1882: 'total patent applications' are from Mitchell (1988), p. 439. Post 1883 data for the *US* and the *UK* are based on 'patents applied to residents' from the World Intellectual Property Organization (WIPO) www.wipo.int/ipstats/en/statistics/patents. Missing years for 'patents applied to residents' are spliced with 'total patent applications'.

Imports and exports: *US*: Imports and exports are measured at current prices. 1870–1969 is obtained from '*Historical Statistics of the United States, Millennial Edition*' (Vol. 5), edited by Carter *et al*. (2006), p. 498; 1970–2009 is from the 'US Bureau of Economic Analysis (BEA)' online database – http://www.bea.gov/. *UK*: 1870–1945 is from Mitchell (1988), pp. 448–454; 1946–2009 is obtained from National Statistics Online (NSO): http://www.statistics.gov.uk/default.asp.

Monetary stock: *US*: 1870–1999: '*Historical Statistics of the United States, Millennial Edition*' (Vol. 3), edited by Carter *et al*. (2006), pp. 601–619; 2000–2009 is from 'US Federal Reserve'. *UK*: 1870–1945: Capie and Webber (1982); 1983–2009: *International Financial Statistics*, Washington: IMF.

Consumer prices: *US*: 'Bureau of Labor Statistics (BLS)': http://www.bls.gov/cpi/#tables. *UK*: 1870–1987 is obtained from the online database compiled by Robert Allen, '*The World Historical Perspective*': http://www.economics.ox.ac.uk/members/robert.allen/WagesPrices.htm; 1988–2009: National Statistics Online (NSO): http://www.statistics.gov.uk/default.asp.

Life Expectancy: *US*: 1870–1932: '*Historical Statistics of the United States, Millennial Edition*' (Vol. 3), edited by Carter *et al.* (2006); 1933–2009: Human mortality database: http://www.mortality.org/. *UK*: 1870–1932: Mitchell (1988); 1933–2009: Human mortality database: http://www.mortality.org/.

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