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Can government policies increase national long-run growth rates?

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Abstract

We obtain time series estimates of the long run growth rates of 17 OECD countries, and test the hypothesis that these are the same across countries. We find that we cannot reject this hypothesis for the first and last three decades of the 20th century. We conclude that: (i) there are few, if any, feasible policies available that have a significant effect on long run growth rates, and; (ii) any policies that can raise national growth rates must be international in scope. The results therefore have bleak implications for the ability of countries to affect their long run growth rates.

J.E.L Classifications: F0, O0, O4

Keywords: Growth, Convergence, Technological change.

1 Introduction

Recent growth theories have suggested a wide variety of mechanisms whereby national economic policies can result in differences in national long run growth rates. The empirical evidence for these theories is mixed, though many studies have found that

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alternative education, research and investment policies, have significant effects on the growth rates of OECD countries.¹ In this paper we propose a simple test of these theories using Maddison's long run data, (Maddison 1995). Specifically we estimate the long run growth rate for each country. We then use the the estimated error variance to test whether the differences in growth rates are significant. If the alternative policy mixes employed across countries have had significant effects on national rates of technological change, then we should be able to reject the hypothesis that national long run growth rates are the same across countries.

We find that for the first and last three decades of the 20th century, we cannot, at any reasonable level of confidence, reject the hypothesis that all the countries were on identical balanced growth paths. Thus, except for the decades around WWII, we find no evidence of country specific effects on long run growth rates from the alternative economic policy packages.

From a policy perspective, therefore, our results are stark. They imply that the alternative choices among the range feasible policy alternatives, have no consequences on long run growth rates. The only exception to this is if the impact of the policies is international in scope, for example via large and ubiquitous technology spill-overs. In either case the results suggest that that the growth rate is primarily determined by international factors, and that the range of feasible policies for increasing the long run growth rate, is very limited.

¹In particular measuring the relevant explanatory factors and controlling for endogeneity are ubiquitous problems. See Temple (1999a) for a recent survey of these issues.

2 Estimating the Trend Growth Rate

2.1 Trend Breaks and β Convergence

Our approach is to estimate the long run growth rate for each country. Thus we wish to consider periods that are long enough to identify the effects of policy choices on long run growth, as opposed to transitions around the trend. This could be problematic if the actual path deviates from the trend growth path for long periods, or if there are significant trend breaks. This section briefly discussed these issues.

The growth rate may deviate from the trend for long periods, if shocks to income levels exhibit strong persistence. In particular Mankiw, Romer and Weil (1992) estimate the rate of convergence to the balanced growth path (hereafter the rate of β convergence) to be approximately 3% per year.² This implies that the half life of a deviation from trend is 24 years. Such strong persistence will make it difficult to obtain accurate estimates of the balanced path growth rate from observations of GDP per worker over time.

Nevertheless, recent panel data studies by Knight and Villaneuva (1993), Islam (1995), Caselli, Esquivel and Lefort (1996), and Lee, Pesaran and Smith (1997) find much faster rates of β convergence. These estimates range from 10-30% per year, implying half lives between 2 and 7 years. Similarly, using time series data, Jones (1995) finds that GDP in OECD countries exhibits very little persistence.³

Further, fast convergence rates are predicted by open economy growth models, such as Foley and Sidrauski (1970). For example, Barro and Sala-i Martin (1995) show that these models generate convergence rates of 10% and higher, when they are cali-

²This finding is also predicted by closed economy neo-classical growth models, where the capital share is interpreted broadly to include human capital.

³Also see Cook (2002) who obtains estimates of convergence rates of 0.4-0.6%.

brated so that the shadow price of capital equals observed ratios of firms market value to capital stock.⁴ Similarly, Landon-Lane and Robertson (2001) show that fast convergence rates are predicted for these models for wide ranges of values of these parameters and for broad values of the capital share. Since the countries in our sample are best characterized as open economies, our *a priori* expectation is that deviations of GDP per capita from its balanced growth path, exhibit little persistence.

Next consider the possibility of breaks in the trend growth rate. It is apparent that the balanced paths of the countries in our sample will not have been constant over the entire 20th century. In particular previous studies, such as Ben David and Papell (1995), have found evidence of trend breaks in the growth rate for a similar sample of countries.⁵ In view of this we begin by estimating the growth rate for relatively small periods of 15 years each. We then test whether consecutive 15 year periods can be aggregated into longer periods. The details of this process, along with the estimating equation, are discussed in the next section.

2.2 Estimation

In estimating the balanced path growth rate we wish to adopt an approach which is parsimonious and yet, can incorporate a wide range of growth models. Specifically consider a data generating process for output per effective worker, \hat{y} , that has the form

$$\ln \hat{y}_{t+1} - \ln \hat{y}_t = \lambda (\ln \hat{y}^* - \ln \hat{y}_t) \quad (1)$$

where $\lambda > 0$ is an error correction parameter that represents the speed of convergence back to equilibrium from any point of disequilibrium. Mankiw et al. (1992) show that

⁴The key parameters in these models is the adjustment costs elasticities of capital and investment. See Brainard and Tobin (1968) for a discussion of the interpretation of the shadow price of capital and Tobin's q .

⁵These center on WWI and WWII for war affected countries, and in the late 1920's for non war affected countries.

the growth process generated by the Solow (1956) and Swan (1956) growth model can be approximated by an equation of this form, and their model has been used to motivate a substantial part of the empirical growth literature. Moreover, (1) can be derived from many other endogenous and exogenous growth models that have a neo-classical production function including the standard Ramsey model, open economy models with adjustment costs, and two sector endogenous growth models.⁶

Next consider the time path produced by (1), when the economy experiences a random productivity shock each period, v_t , where $E(v_t) = 0$. As shown in Appendix B, the resulting path generated by (1) can be written as an invertible autoregressive moving average specification for the growth rate in output. Thus the growth rate of output can be represented as an infinite order autoregressive process with coefficients that converge to zero. This can be approximated by the following finite order autoregressive model.

$$\Delta \ln y_{it} = \varphi_{i,0} + \sum_{j=1}^{P_i} \varphi_{i,j} \Delta \ln y_{i,t-j} + \epsilon_{it}, \quad (2)$$

where P_i is the finite lag length, and Δ represents the first difference operator. As discussed above, if convergence rates are fast, the magnitude of the autoregressive parameters, will quickly converge to zero. Hence (2) will be a good approximation to the an infinite autoregressive process, even for small values of P_i .

Thus (2) can be regarded as describing the growth rate of a range of models with neo-classical production functions. Alternatively it can be regarded as a reduced form expression for any model that exhibits a trend with some persistence in deviations from the trend.

⁶For example, the Uzawa-Lucas model, (Uzawa (1964), Lucas (1988)). For further discussion of these models see Barro and Sala-i Martin (1995).

Assuming that $\Delta \ln y$ is stationary, the unconditional mean growth rate is

$$\mu_i = \frac{\varphi_{i,0}}{1 - \sum_{j=1}^{P_i} \varphi_{i,j}}. \quad (3)$$

If there has been no change in the parameters that determine the balanced growth path, then μ_i will simply equal the balanced path growth rate. Moreover, using the neo-classical growth model, we can interpret μ_i as the rate of labour augmenting technological progress.⁷

2.3 The Data and Stationarity

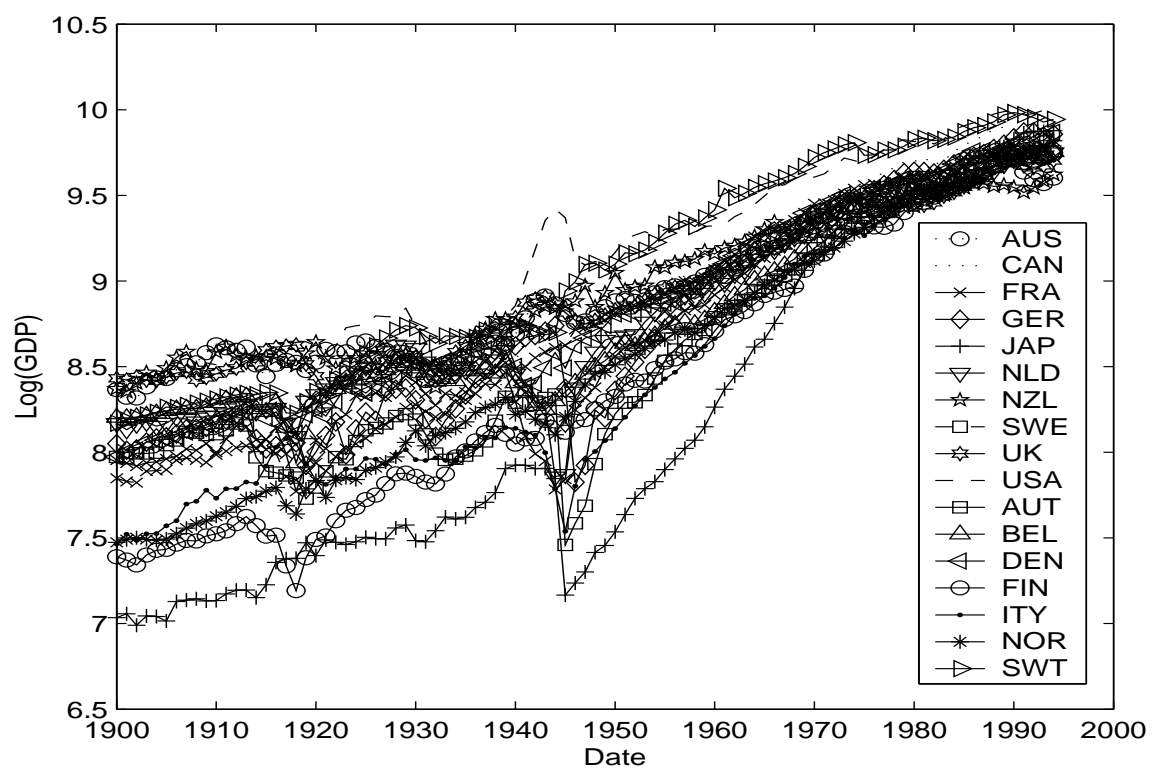
Before estimating (2), we first investigate whether the series $\ln y_{it}$, is best represented as trend stationary or difference stationary series, for each country. The data we use is the annual real GDP per capita for the period 1900 until 1994, measured in 1990 Geary-Khamis dollars, (Maddison 1995).⁸

A visual inspection of the data, given in Figure 1, shows that $\ln y_{it}$ is non-stationary for each country, i . For each country, we therefore use an augmented Dickey-Fuller (ADF) test, in order to determine whether the non-stationarity is due to the presence of a unit root or a time trend. The results of these tests, given in Table 1, show that for all countries, a unit root for $\ln y_{it}$ cannot be rejected. Thus the ADF tests confirm that it is appropriate to estimate growth rate using first differences, as in (2).

⁷In the neo-classical model, the existence of a balanced path requires that technological change is labour augmenting (Harrod neutral). Empirically, however, factor shares are relatively constant over time. This suggests that the elasticity of substitution between factor inputs is approximately equal to unity. In this case any form of factor augmenting technological change can be expressed in labour augmenting terms.

⁸Table 1 gives a list of countries in the sample.

Figure 1: Real GDP:1990-1994



3 Testing for the equality of μ across countries

We therefore proceed with estimating (2) for each country. In order to account for any cross-sectional heteroskedasticity and contemporaneous correlation we use the seemingly unrelated regression (SUR) estimator of Zellner (1962).⁹ The system is estimated using iterated feasible generalized least squares (IFGLS), and value of the lag length P_i is chosen to minimize Akaike's Information Criterion.

In order to obtain estimates of μ for particular subsamples, (2) is modified to include dummy variables for each subsample. That is, for country i , if there are N subsamples, (2) becomes

$$\Delta \ln y_{it} = \sum_{k=1}^N \delta_{ik} D_{kt} + \sum_{j=1}^{P_i} \varphi_{i,j} \Delta \ln y_{i(t-j)} + \epsilon_{it} \quad (4)$$

and the growth rate for subsample k is

$$\mu_i^k = \frac{\delta_{ik}}{1 - \sum_{j=1}^{P_i} \varphi_{i,j}}. \quad (5)$$

Note that this assumes that only the trend growth rate changes between the different subsamples so that the persistence properties remain unchanged over the whole sample.

Finally we consider whether the trend growth rates, μ_i , are equal across countries. For a given time period the null and alternative hypotheses are

$$H_0 : \mu_1 = \mu_2 = \dots = \mu_{17} \quad v. \quad H_A : \mu_i \neq \mu_j \text{ for some } i \neq j. \quad (6)$$

The null hypothesis is then tested using a non-linear Wald test.

⁹The hypothesis of a diagonal covariance matrix is rejected. The Breusch-Pagan LM test statistic for a diagonal covariance matrix is 1186.1 and is distributed as χ^2 with 136 degrees of freedom.

4 Results

As anticipated, the test for equality of growth rates between the countries in our sample was rejected for the whole period, 1904-94. The Wald statistic, reported in Table 2, was 29.46 with a p-value of 0.021, and hence the null can be rejected the 5% level. Next we allow for trend breaks. We therefore divide the sample into six periods of approximately 15 years each, and estimate (4) for each period. If H_0 cannot be rejected for two consecutive periods, we then test whether the value of μ is constant across the adjacent time periods. We then aggregate these adjacent periods where when we cannot reject the hypothesis that μ is the same across time.¹⁰ This leads us to consider whether the hypothesis of a common μ across countries can be rejected for two periods of approximately three decades each, 1904-30 and 1961-94. The definitions of the final sub-periods used and the results from the non-linear Wald tests can be found in Table 2 below.

It can be seen that for these thirty year periods, where the trend growth rate appears to be constant for each country, we cannot reject the hypothesis that μ is the same across countries. For both periods the probability of falsely rejecting the null hypothesis is approximately 50%. Hence for these periods, 1904-1930 and 1961-1994, we find no significant difference in the trend growth rates of these 17 countries.

Finally we note that there is strong evidence that the sub-samples cannot be aggregated further, since the tests for equality of growth rates between the adjacent periods are all rejected at the 5% level.¹¹ Thus these intervening years mark a clear break from the parallel growth paths at the start and end of the century. Interestingly,

¹⁰This procedure is discussed further in Appendix A and the results for these 15 years periods are given in Table A.1.

¹¹Jones (1995) and Ben David and Papell (1995) conduct tests for differences in mean growth rates on a country by country basis. Jones (1995) finds no evidence for a shift in the mean growth rate for the USA, but does find evidence of a mean shift in other OECD countries. Ben David and Papell (1995) similarly find evidence of a shift in the mean growth rate for their sample, including the USA.

the third panel of Table 2 also shows that we cannot reject the hypothesis that the common value of μ across countries for period IV (1961-1994) was the same as the common value across countries for period I (1904-1930). Thus we cannot exclude the possibility that each country has returned to the same balanced growth path that they began on at the start of the century. Certainly we find little evidence that the trend rate increased or decreased over the century.

5 Interpretation and Discussion

In contrast to much of the existing empirical growth literature, we have not attempted to determine the significance of any particular explanatory variables. Rather, we have asked a more fundamental question - are the measured differences in growth rates statistically significant? Our finding is that they are not significant for most of the last century, excluding only the WWII and post war recovery periods. This leads us to question whether any relevant policy alternatives can place a country on a higher growth path than other countries at similar levels of development.

To see this consider the broad alternative policy implications of countries having the same long run growth rates. The possible explanations are that either: (i) there are no politically feasible policies that can increase the national long run growth rate; (ii) some feasible long run growth policies exist, but they were not implemented by any of the countries in our sample; (iii) some feasible national long run growth policies exist, but these were all implemented by all countries, or; (iv) that any feasible national long run growth policies, have equivalent effects on international growth rates, through, for example, knowledge spill-overs and externalities from internationally traded capital goods.

Of these possibilities, (ii) seems the least plausible. It is likely that if any politically

feasible growth strategies existed, they would have been undertaken by some government. The alternative, given in (iii), is that all the countries in our sample adopted the same long run growth policies. If we rule out coincidence, this implies that there were no politically feasible alternatives to these decisions. For example, radical tax reform might potentially increase growth, but this is not on the political agenda of the countries in our sample.¹² Thus (i), and (iii) lead to the conclusion that there were no feasible alternative policies that would have increased national growth rates.

The qualification to this conclusion is given by (iv). If some of the different policy packages employed across countries did affect domestic growth rates, the results imply that these must have had similar impacts on other countries in the sample. For example, policies that affect the rate of scientific research and the creation of new knowledge, might also generate substantial international knowledge and productivity spill-overs. The range of domestic factors that have such a strong international consequences, must be limited however. For example, this may be a plausible description of the effects of the level of subsidies to basic science in large countries, such as the USA. For small economies such, as Australia, New Zealand or Switzerland however, it is less plausible.

A second implication of our results relates to the convergence and catch-up hypotheses. The results do not contradict previous studies that find that “catch-up” in income levels occurred over last century, for many of these countries, (Baumol 1986). Specifically we reject the hypothesis that the trend growth rate was the same for each country, from 1904-1994. Our results show, however, that catch-up was not steady, but was centered on the middle of the century around WWII. This is consistent with Ben David and Papell ((1995) and (2000)), who estimate trend breaks for OECD countries individually.¹³ Since catch-up appears to be a result of a trend break how-

¹²Similarly, consider radical but inegalitarian education reforms.

¹³Time series tests of convergence, such as Bernard and Durlauf (1995) find evidence of convergence

ever, it is likely that exogenous political and social changes, rather than economic policy, may have been important factors in determining the timing and extent of catch-up.

Finally we consider the relationship between these findings and other empirical growth literature. Our results indicate that each country's balanced path growth rate primarily determined by international, rather than domestic factors. They therefore provide compelling empirical support for recent models that emphasize the importance of international links in determining productivity growth, such as Eaton and Kortum (1996), Parente and Prescott (2000) and Acemoglu and Ventura (2001).¹⁴

The results do not necessarily contradict models in which domestic policy choices can explain the cross sectional variation in growth rates. Nevertheless they suggest, for example, that among developed market economies, the differences in education attainment and R&D spending are not large enough to have a significant effect on their relative growth rates. Hence these models appear to be less relevant to developed market economies and more relevant to issues facing developing economies.¹⁵

6 Conclusion

Many growth theories suggest that domestic policy choices are an important determinant of national long run growth rates. Empirical support for these theories is mixed

among some pairs of countries only. See Durlauf and Quah (1999) for a survey of these results.

¹⁴The finding of parallel growth paths also complements Evans (1998), who finds that GDP from 1900-1994 among these countries is co-integrated. In contrast to Evans (1998), however, our results do not reject the long run convergence hypothesis across the entire sample of countries in Maddison's data. Moreover, our findings can be viewed as support for the premise of the Solow (1956) and Swan (1956) model. They also provide additional evidence against the existence of scale effects as a determinant of the long run growth rate, at the national level. See also Jones (1999).

¹⁵For example Bassanini and Scarpetta (2001) find empirical support for the Uzawa (1964), Lucas (1988) model in a sample of OECD countries. Our results caution that these results may be insignificant once we allow for the time series variation in growth rates. See also other recent empirical studies of OECD countries such as Guellec and de la Potterie (2001), Bassanini, Scarpetta and Hemmings (2001) and Bassanini, Scarpetta and Visco (2000).

however. We have considered an alternative empirical test that sets a minimum standard for any theory of growth relating domestic policy to national long run growth rates. By estimating the trend growth rates of 17 OECD countries, we found that for the first three and last three decades of the century, the hypothesis that the trend growth rates are the same across countries, cannot be rejected at any reasonable level of confidence. Thus, except for the decades around WWII, there is no evidence of country specific effects on long run growth rates.

The results therefore have stark implications for the ability of most countries to determine their own long run growth rates. The many policy packages used across these countries, including differences in tax, research, education and investment, did not have significant long run effects on relative growth rates. We conclude therefore that long run growth rates are determined by international factors, and are insensitive to national policies, especially for small countries. This implies severe restrictions of the ability of most governments to increase national long run growth rates. Nevertheless our results provide empirical support for a number of recent growth models that have emphasized the importance of international links in determining national productivity growth.

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A Test Results for 15 year samples

We allow for trend breaks, by dividing the sample into six periods of approximately 15 years each, and estimating (4) for each period. As shown in Table A.1, using non-linear Wald tests, we find that for the last two post WWII periods, 1961-75 and 1976-1994, the hypothesis that there is a common value of μ across countries, cannot be rejected at any reasonable level of confidence. Likewise the null hypothesis cannot be rejected for the first two periods of the sample 1904-1915 and 1916-1930. We find that the null hypothesis can only be rejected for the two fifteen year periods directly before and after WWII.

Next we test whether the value of μ are constant across the consecutive time periods. The results of a non-linear Wald test, are shown in Table A.2. We find that we cannot reject the hypothesis that μ was the same in the period 1904-1915 as it was in the next period, 1916-1930. Similarly we cant reject the null that μ was the same in 1961-75 as it was in 1976-1994. In view of this we then aggregate these consecutive periods where when we cannot reject the hypothesis that μ is the same, leading to the period 1904-30 and 1961-94, as discussed in the main text.

B Derivation of Equation 2

We assume that output per worker, y_t , is produced using a constant returns to scale function of capital per worker, k_t and labour services per worker, h_t , $y_t = f(k_t, h_t)$. Hence output per effective worker is $\hat{y}_t = y_t/h_t = f(\hat{k}_t, 1)$. Since factor shares are known to be relatively constant over long periods of time, we assume further that $f(k_t, h_t)$ can be approximated by the isoelastic functional form. We therefore define $d \ln y / d \ln k = \alpha < 1$ and $d \ln y / d \ln h = 1 - \alpha$, as the constant output elasticities. Note that this gives $d \ln \hat{y} / d \ln h = -\alpha$.

We assume that labour productivity growth has an expected and an unexpected component. Specifically

$$\ln h_{t+1} = \ln h_t + g + v_{t+1} \quad (\text{B.1})$$

where g is a constant and v is a normally distributed random variable with a mean of zero, $E_t v_{t+1} = 0, \forall t$.

As discussed in the text, the growth of output per effective worker in many models that assume this neoclassical production function, can be described by Equation (1). Thus, using the preceding results, the instantaneous effect of the contemporaneous shock, v_{t+1} , on the growth rate of output per effective worker is

$$\Delta \ln \hat{y}_{t+1} = \lambda (\ln \hat{y}^* - \ln \hat{y}_t) - \alpha v_{t+1} \quad (\text{B.2})$$

By updating and substitution, we arrive at an expression for the growth rate of output per effective worker in some arbitrary future period τ , as a consequence of a one off unanticipated productivity shock at time t .

$$\ln \hat{y}_{\tau+1} - \ln \hat{y}_\tau = \lambda(1 - \lambda)^{\tau-t} \alpha v_t \quad (\text{B.3})$$

Thus the growth rate of output per worker at time τ , $\Delta \ln y_{\tau+1} = \Delta \ln \hat{y}_{\tau+1} + \Delta \ln h_{\tau+1}$, generated from an infinite history of unexpected shocks is

$$\ln y_{\tau+1} - \ln y_{\tau} = g + (1 - \alpha)v_{\tau+1} + \alpha\lambda \sum_{s=0}^{\infty} (1 - \lambda)^s v_{\tau-s} \quad (\text{B.4})$$

Equation (B.4) describes growth path that evolves as agents adjust their forward looking investment decisions to realized, but unanticipated, shocks, for a given balanced path. It can be seen that the growth rate follows a moving average (MA) process, where the lagged error coefficients are exponentially decaying over time. Following Koyck (1954), (B.4) can be transformed into a first order auto-regressive model with a first order moving average error term,

$$\Delta \ln y_t = \lambda g + (1 - \lambda)\Delta \ln y_{t-1} + \nu_t, \quad (\text{B.5})$$

where $\nu_t \equiv \epsilon_t + \rho\epsilon_{t-1}$ and $\rho \equiv -1 + \lambda/(1 - \alpha)$. Empirical evidence suggests that $\lambda < 1 - \alpha$, and so $|\rho| < 1$. In this case (B.5) is an invertible ARMA(1,1) model with an $AR(\infty)$ representation,

$$\Delta \ln y_t = \theta_0 + \theta_1 \Delta \ln y_{t-1} + \theta_2 \Delta \ln y_{t-2} + \dots + \epsilon_t. \quad (\text{B.6})$$

where the coefficients $\theta_0, \theta_1, \dots$, decline monotonically in absolute value. Hence this can be approximated by an autoregressive equation with a finite lag length. Truncating (B.6) to length $P < \infty$ gives equation, (2) in the text.

C Technical Appendix

These notes contain details of the derivation of equation (2) and in particular the derivation of equation B.4 in Appendix B.

As in the text, consider the data generating process for output per effective worker, $\ln \hat{y}_t$.

$$\ln \hat{y}_{t+1} - \ln \hat{y}_t = \lambda (\ln \hat{y}^* - \ln \hat{y}_t) \quad (\text{C.7})$$

where $\lambda > 0$ represents the speed of convergence back to equilibrium from any point of disequilibrium. We think of this as an investment plan for output in period $t + 1$, based on realized values variables in period t . Thus more specifically (C.7) can be written

$$E_t \ln \hat{y}_{t+1} - \ln \hat{y}_t = \lambda (\ln \hat{y}^* - \ln \hat{y}_t) \quad (\text{C.8})$$

or

$$E_t \ln \hat{y}_{t+1} = \lambda \ln \hat{y}^* + (1 - \lambda) \ln \hat{y}_t \quad (\text{C.9})$$

Next we assume that output per worker, y_t , is produced using a constant returns to scale function of capital per worker, k_t and labour services per worker, h_t , $y_t = f(k_t, h_t)$. Hence output per effective worker is $\hat{y}_t = y_t/h_t = f(\hat{k}_t, 1)$. Since factor shares are known to be relatively constant over long periods of time, we assume further that the production function can be approximated by the Cobb-Douglas form.

$$\ln y_t = \alpha \ln k_t + (1 - \alpha) \ln h_t \quad (\text{C.10})$$

where $\alpha < 1$. Hence $d \ln y / d \ln k = \alpha < 1$ and $d \ln y / d \ln h = 1 - \alpha$.

Next we assume that labour productivity growth has an expected and an unexpected component. Specifically

$$\ln h_{t+1} = \ln h_t + g + v_{t+1} \quad (\text{C.11})$$

where g is a constant and v is a normally distributed random variable with a mean of zero, $E_t v_{t+1} = 0, \forall t$. Hence we have

$$E_t \ln h_{t+1} = g + \ln h_t \quad (\text{C.12})$$

Now using (C.12) and (C.10)

$$\begin{aligned} E_t \ln y_{t+1} &= \alpha \ln k_{t+1} + (1 - \alpha) E_t \ln h_{t+1} \\ &= \alpha \ln k_{t+1} + (1 - \alpha)(g + \ln h_t) \end{aligned} \quad (\text{C.13})$$

The difference between actual and expected output per worker is then obtained by subtracting (C.13) from (C.10).

$$\begin{aligned} \ln y_{t+1} - E_t \ln y_{t+1} &= (1 - \alpha)(\ln h_{t+1} - E_t \ln h_{t+1}) \\ &= (1 - \alpha)v_{t+1} \end{aligned} \quad (\text{C.14})$$

In terms of output per effective worker the equivalent expression to (C.14) is

$$\begin{aligned}\ln \hat{y}_{t+1} - E_t \ln \hat{y}_{t+1} &= \alpha(k_{t+1} - (h_t + g + v_t)) - (\alpha(k_{t+1} - (h_t + g))) \\ &= -\alpha v_{t+1}\end{aligned}\tag{C.15}$$

Note that from (C.15) and (C.14) there is no difference between the actual and expected capital stock, at time $t + 1$. After a shock is realized however, agents will adjust their investment plans according to (C.7).

We may now use these results to consider the instantaneous effect of the contemporaneous shock, v_{t+1} , on the growth rate of output. Substituting (C.9) into (C.15) gives

$$\ln \hat{y}_{t+1} = \lambda \ln \hat{y}^* + (1 - \lambda) \ln \hat{y}_t - \alpha v_{t+1}$$

Then subtracting $\ln \hat{y}_t$ from both sides gives the growth rate of output per effective worker.

$$\Delta \ln \hat{y}_{t+1} = \lambda (\ln \hat{y}^* - \ln \hat{y}_t) - \alpha v_{t+1}\tag{C.16}$$

where $\Delta \ln \hat{y}_{t+1} \equiv \ln \hat{y}_{t+1} - \ln \hat{y}_t$. The growth rate of output per worker is obtained by adding $h_{t+1} - h_t$ to both sides of (C.16). Using (C.11) this gives

$$\Delta \ln y_{t+1} = g + (1 - \alpha)v_{t+1} + \lambda (\ln \hat{y}^* - \ln \hat{y}_t)\tag{C.17}$$

Thus the effect of unexpected productivity growth on the growth rate of output per

worker is simply given by elasticity of output with respect to labour $1 - \alpha$.

Next we consider the effect of unanticipated shocks, $v_{t+1}, v_{t+2} \dots$, on the future growth path. To see this, first suppose that the economy is on a steady state at time t , so that $\hat{y}^* = \hat{y}_t$, and consider a single unanticipated shock, v_{t+1} .

Substituting $\hat{y}^* = \hat{y}_t$ in (C.16), we have $\Delta \ln \hat{y}_{t+1} = \ln \hat{y}_{t+1} - \ln \hat{y}^* = -\alpha v_t$. Hence $\ln \hat{y}^* - \ln \hat{y}_{t+1} = \alpha v_t$, so that updating (B.2) one period, and substituting the preceding expression gives

$$\Delta \ln \hat{y}_{t+2} = \lambda \alpha v_{t+1} \quad (\text{C.18})$$

Similarly updating (C.16) again gives

$$\Delta \ln \hat{y}_{t+3} = \lambda (\ln \hat{y}^* - \ln \hat{y}_{t+2}) \quad (\text{C.19})$$

Noting that $\ln \hat{y}^* - \ln \hat{y}_{t+2} = \ln \hat{y}^* - \ln \hat{y}_{t+1} - \Delta \ln \hat{y}_{t+2}$, and using (C.18), this becomes

$$\Delta \ln \hat{y}_{t+3} = \lambda (\alpha v_{t+1} - \lambda \alpha v_{t+1}) = \lambda (1 - \lambda) \alpha v_{t+1} \quad (\text{C.20})$$

By repeating this process of updating and substitution, we arrive at an expression for the growth rate of output per effective worker in some arbitrary future period τ , as a consequence of a one off unanticipated productivity shock at time t .

$$\ln \hat{y}_{\tau+1} - \ln \hat{y}_\tau = \lambda (1 - \lambda)^{\tau-t} \alpha v_t \quad (\text{C.21})$$

Next we can consider the effect of a series of unanticipated shocks, v_t , on the growth rate at time τ , by summing the effects of shocks in each year, as given in (C.21).

$$\ln \hat{y}_{\tau+1} - \ln \hat{y}_{\tau} = \alpha \lambda \sum_{s=0}^{\tau-t} (1 - \lambda)^s v_{t+s} \quad (\text{C.22})$$

Finally, to derive an equation suitable for estimation we rewrite (C.22) as an historic growth path looking back from time τ . Thus we allow for the time when $\hat{y} = \hat{y}^*$, to approach the infinite past.

$$\ln \hat{y}_{\tau+1} - \ln \hat{y}_{\tau} = \alpha \lambda \sum_{s=0}^{\infty} (1 - \lambda)^s v_{\tau-s} \quad (\text{C.23})$$

Then expressing (C.23) in terms of output per worker and including the contemporaneous unanticipated shock

$$\ln y_{\tau+1} - \ln y_{\tau} = g + (1 - \alpha)v_{\tau+1} + \alpha \lambda \sum_{s=0}^{\infty} (1 - \lambda)^s v_{\tau-s} \quad (\text{C.24})$$

which is (B.4) in the appendix.

Table 1: Summary of Augmented Dickey-Fuller Results

Country	t-stat	Lag Length
Australia (AUS)	-1.97	1
Canada (CAN)	-0.12	1
France (FRA)	-1.78	2
Germany (GER)	-2.33	4
Japan (JAP)	-1.51	2
Netherlands (NLD)	-2.20	2
New Zealand (NZL)	-2.09	1
Sweden (SWE)	-1.90	1
United Kingdom (UK)	-2.08	3
USA (USA)	-2.80	1
Austria (AUT)	-2.04	1
Belgium (BEL)	-1.83	1
Denmark (DEN)	-2.02	2
Finland (FIN)	-2.43	1
Italy (ITY)	-1.91	1
Norway (NOR)	-1.88	1
Switzerland (SWT)	-1.91	1

Table 2: Results from Wald Tests for equality of growth rates

Period	Years	Wald Statistic	Degrees of Freedom	p-value
Test for Whole Sample				
	1904-1994	29.46	16	0.021
Tests within sub-periods				
I	1904-1930	15.27	16	0.504
II	1931-1945	45.18	16	0.000
III	1946-1960	33.71	16	0.006
IV	1961-1994	15.76	16	0.470
Tests between sub-periods				
	I and II	60.59	33	0.002
	II and III	85.73	33	0.000
	III and IV	49.65	33	0.032
	I and IV	39.18	33	0.212

Table A.1: Wald Tests for equality of μ : 15 Year Periods

Period	Years	Wald-statistic	Degrees of Freedom	p-value
1	1904-1915	11.46	16	0.781
2	1916-1930	16.31	16	0.432
3	1931-1945	46.09	16	0.000
4	1946-1960	33.55	16	0.006
5	1961-1975	12.29	16	0.717
6	1976-1994	11.73	16	0.762

Table A.2: Wald Tests for a constant value of μ across time periods

Period	Wald-statistic	Degrees of Freedom	p-value
5 & 6	26.17	33	0.794
3 & 4	85.90	33	0.000
1 & 2	27.93	33	0.718