Does Technical Change Reduce Growth Volatility?

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Abstract:
This paper uncovers a link between technical change and growth volatility: Growth volatility is significantly lowered by a country's ability to publish more scientific and technical journal articles or attain a higher rate of total factor productivity growth, even after controlling for the income level and unobserved country- and time-fixed effects in panel data regressions. This link is unlikely the result of weak data, simultaneity bias or specification errors. Our results also show that property rights institutions, when measured by executive constraint, are found to have significant effects on growth volatility either directly or indirectly through technical change.

Keywords: Technical change, Growth volatility, Institutions

JEL classifications: O11, O33, E32

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1. Introduction

One of the big questions in economic growth is: Why do the growth rates of some countries vary so much over time? Developing countries, in particular, have experienced enormous growth fluctuations throughout their development.[1] From Table 1, we can observe two important phenomena about growth volatility in the past 40 years. First, developing countries on average experienced growth volatility that is roughly two to three times of those of the industrialized economies. The average standard deviation of GDP growth rates for OECD economies, for example, is 2.8 percent during 1980-84, while the same figure for the rest of the world is 6.2 percent. This reflects a large disparity in uncertainty and risk faced by individuals between industrialized and developing countries. Second, there appears that growth volatility has diminished by roughly 50 percent since the late 1980s for the industrialized OECD countries. (The standard deviation for the GDP growth rates decreases from roughly 3 percent to 1.5 percent). At the same time, growth also becomes less volatile for developing countries. (The standard deviation for the GDP growth rates decreases from roughly 6 percent to 4 percent).

Table 1: Growth Volatility in OECD Countries and Rest of the World 1960-2000

	Average standard deviation of real GDP per capita growth rates (%)								
	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-97	98-00
OECD	2.8	2.5	2.6	3.0	2.8	1.8	3.0	1.5	1.5
Rest of the world	6.1	4.9	5.5	6.2	6.1	4.8	5.3	4.3	4.0

Notes:

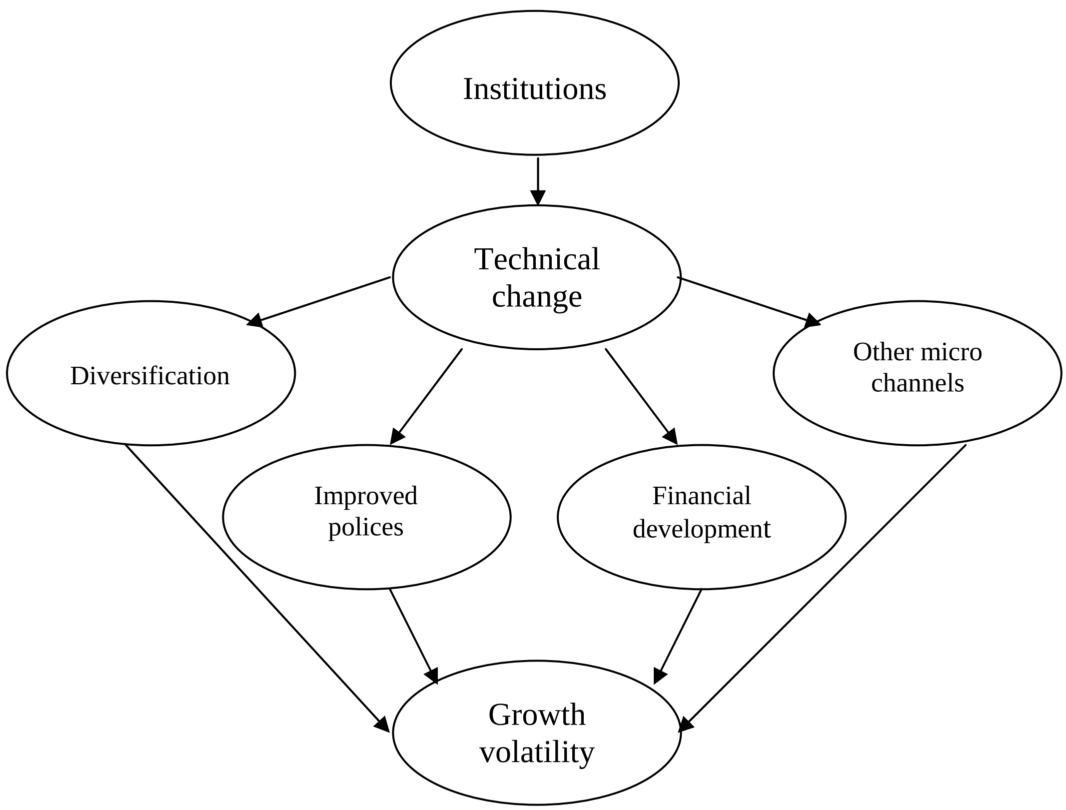
1. Standard deviations of different time periods are calculated from the growth rates of GDP per capita in constant price (RGDPCH) which are taken from *Penn World Table 6.1*.
2. Currently there are 30 OECD countries and the rest of the world comprises 145 countries. See Appendix A for a list of countries in both samples.

The question we focus on in this paper is what account for the substantial differences in growth volatility across countries and over time as shown in Table 1. We propose a framework for analyzing growth volatility in Figure 1, which presents a highly stylized explanation of growth volatility. First, the framework depicted by Figure 1 highlights the

[1] In this paper, we use the terms growth volatility, macroeconomic fluctuations and business-cycle volatility interchangeably.

centrality of technical change in explaining growth volatility. The key hypothesis of this paper is to test whether increasing the level of technical change of a country, on average, reduces its growth volatility. Second, Figure 1 suggests that institutions, in particular, property rights institutions, can affect growth volatility either directly or indirectly through technical change. It should be stressed, however, that the framework depicted by Figure 1 highlights the arguments underlying the link between technical change and growth volatility, which by no means is a complete picture but at best a partial explanation of growth volatility.

Figure 1: The Link between Technical Change and Growth Volatility



Our main hypothesis concerns about the link between the level of technical change and growth volatility. We contend that a country with little technological capacity is likely to experience higher growth volatility. Some of the possible explanations for this relationship can be summarized as follows:

1. A country with little technological know-how has limited capacity to produce a variety of value-added products, resulting in an economy heavily dependent on a single sector or even a single commodity. A positive demand shock for the country's product would generate a higher growth rate than those countries that are more diversified. Conversely, when an external shock such as a deterioration of terms of trade hits, the country would be facing a more severe downturn.
2. Countries which have higher research and technical capacity are better informed and prepared to formulate stabilization policies to reduce growth volatility. Effective stabilization policies, such as inflation targeting, require accurate and timely macroeconomic data on the economy, which can only be realized by improvement in knowledge and skills or technical change.
3. Technical change allows possible development in financial systems and more developed financial systems imply a reduced impact of asymmetric information problems, as financial institutions become more capable of identifying projects with higher probability of failure. On the other hand, arguments can also be made for that a faster pace of financial development without proper supervision and sound institutions may actually accentuate growth volatility. Thus, the net effect of financial development on growth volatility is unclear.
4. Countries with little indigenous technological know-how rely primarily on foreign investment and technology. The uncertain nature of foreign investment and technology, especially low-tech, foot-loose industries, adds to increased output volatility for these economies.
5. Technical change can be defined in a general sense that includes management skills and national technological systems, so that countries without the technological know-how have little capacity to prevent and deal with effectively any unforeseen events such as natural disasters or sudden outbreaks of diseases. In essence, a higher level of technological capacity provides a better safety net for a country to cope with unexpected events. For example, an early warning system for and basic knowledge of tsunami could have saved many lives in Asia in December 2004.

The variables listed above are not meant to be exhaustive, but are believed to be some illustrations of why growth volatility can be affected by the level of technical change. More importantly, this paper does not even attempt to disentangle each of these technological channels on growth volatility. Rather, this paper focuses only on uncovering empirical evidence of an overall link between the level of technical change and growth volatility. Our results show that growth volatility is significantly lowered by a country's ability to attain a higher level of technical change measured by the number of publications in scientific and technical journals or total factor productivity growth, even after controlling for the initial income level, population growth and unobserved country- and time-fixed effects in panel data regressions.

Our second hypothesis concerns about the deeper determinants of growth volatility. A current debate in the growth literature relates to the relative importance of institutions for long-run economic growth. We take up this theme by testing the hypothesis that strong institutional quality reduces growth volatility directly as well as indirectly through technical change. In our approach, we evaluate the direct effects of property rights institutions on growth volatility as well as its indirect effects through technical change.

We expand the macroeconomic literature on the original idea that the level of technical change affects growth volatility. First, there have been few theoretical and empirical studies in the literature explicitly putting forward the arguments or evidence for the stabilizing effect of technical change on output growth. As far as the author aware, this study is the first to point out the empirical regularity of the stabilizing effect of technical change on growth. Second, this study, unlike studies that focus on explaining a marked decline in output volatility in the US or some OECD economies since the 1980s, includes large cross-country panel for the past 40 years in our study. This approach allows us to draw much generalized conclusions, while controlling for unobserved country and time fixed-effects over the past 40 years. Third, we use alternative definitions of technical change and growth volatility to minimize measurement errors. Technical change is measured by both the number of scientific and technical journal publications and total factor productivity growth. We show, regardless of how technical change or growth volatility are measured, that the results clearly point to a significant link between the level of technical change and growth volatility.

Section 2 reviews literature in the area of growth volatility and discusses how the present study relates to this body of literature. Section 3 discusses the measurement of technical change and growth volatility and the theories behind these measurements. Section 4 presents and discusses test results for the main hypothesis which links technical change to growth volatility. Then, Section 5 presents and discusses test results for the second hypothesis which attempts to link technical change to property rights institutions, followed by concluding remarks in Section 6.

2. Literature Review

There is already an extensive body of literature on macroeconomic volatility. The first stream of literature that relates technical change to output fluctuations is the real-business-cycle (RBC) models which emerged in the early 1980s with the work of Nelson and Plosser (1982), Kydland and Prescott (1982) and Long and Plosser (1983).[2] According to RBC models, output fluctuations are induced by the stochastic variations in technology. Kydland and Prescott (1991) estimated the importance of variations in the Solow technology parameter as a source of aggregate fluctuations and find that they were a major source accounting for about 70 percent of the variance of US postwar cyclical fluctuations. Our idea differs from the RBC models in that the source of macroeconomic volatility is due not so much to the variations in technology, but mainly to the lack of technological capabilities for a country to cope with dynamic shocks.

The second stream of literature attributes the source of macroeconomic volatility directly to institutional weaknesses. The idea that institutional quality directly affects macroeconomic volatility was first discussed in Sah (1991). According to him, growth in societies with weak democratic institutions is more volatile than societies with strong democratic institutions due to human fallibility. Rodrik (1999) develops a theory that is consistent with Sah's conjecture. He argues that domestic social conflicts magnify the adverse effects of external shocks, like deterioration of the terms of trade. Societies with poor institutional quality where different interest groups act in opportunistic ways in the face of a reduction in economic surplus may not agree on the most efficient adjustment policies, which causes surplus to be reduced even further. Almeida and Ferreira (2002)

[2] See King and Rebelo (1999) for a survey of this literature.

empirically test Sah's conjecture and find that both cross-country and within-country variability in growth rates are higher for more centralized societies than less centralized ones. They also show that both the best and worst performers in terms of growth rates are more likely to be autocracies.

Acemoglu, Johnson, Robinson and Thaicharoen (2003) find strong empirical evidence to support a causal link between institutions and growth volatility. They, however, fail to find the channels through which institutions affect macroeconomic volatility, as pointed out by Fogli (2003) in his comment on their study that: "… the authors find that institutions have an important role in explaining volatility, but they cannot identify the channel through which this effect operates" (p. 131). Fogli suggests that total factor productivity (TFP) can be an important factor in explaining macroeconomic volatility. In this paper, we confirm Fogli's suggestion to show that the level of technology is an important variable in explaining cross-country and over-time differences in growth volatility.

The third stream of literature on growth volatility focuses on the link between volatility and growth. Since there are many reasons supporting either a positive or negative link between volatility and growth, the nature of causality between volatility and growth has to be settled empirically. Ramey and Ramey (1995), for example, find empirical evidence to support that countries with higher output volatility have lower growth. On the contrary, Mills (2000), among others, find that higher standard deviations of output growth are associated with higher mean growth rates. The focus in this paper is not on the determinants of the long-run growth rate, which has already received enormous attention. Rather, we explore the relatively new idea of the stabilizing effect of technology on the economy.

Other recent studies attempt to explain why output volatility has diminished substantially over last fifty years in the US. McConnell and Perez-Quiros (2000), Blanchard and Simon (2001) and Stock and Watson (2002) document the long and large decline in output volatility in the US. They conclude that improvements in policy (such as better and more credible monetary policy and inflation targeting), technical change (such as improved inventory management), and good luck (in the form of productivity and commodity price shocks) are the main reasons accounting for the decline in the US's output volatility.

Finally, many studies in the area focus on the causes of economic and financial crises in emerging economies. These studies emphasize on the role of financial factors and macroeconomic problems as the main causes of their sufferings. For example, Kaminsky and Reinhart (1999) find that crises in many emerging economies occur "… as the economy enters a recession, following a prolonged boom in economic activity that was fueled by credit, capital inflows and accompanied by an overvalued currency" (p. 473). In the aftermath of 1997 Asian financial crisis, Feldstein (2002) conclude that policies such as exchange rate regimes, capital account convertibility, foreign exchange, reserves and financial supervision are important factors in determining the likelihood of future crises. The current paper does not fit into this stream of literature since our dependent variable is growth volatility, rather than economic and financial (banking or currency) crises. Furthermore, our main explanatory variables are the level of technology and institutions, rather than variables relating to financial sectors.

3. Measures of Technical Change and Growth Volatility

One of the key variables in this paper is technical change. Technical progress, as defined by neoclassical economics, enables the economy to obtain greater outputs from the same inputs as time proceeds. This concept of technical change is related to production capacity and there is a wide selection of parametric and non-parametric methods for estimating technical change which are consistent with the neoclassical theory if certain preconditions are met. Solow residual or total factor productivity (TFP) growth, for example, is a widely-used measure of technical change which is consistent with the neoclassical theory. We will use TFP growth for checking the robustness of the link between technical change and growth volatility in the next section.

Technical change can also refer to technological capabilities. Schumpeter defined three phases in the process of technical change: invention, innovation, and diffusion. Using Freeman's (1974) definitions, invention is an idea, a sketch or a model for a new improved device, product, process or system. An innovation is accomplished only with the first commercial transaction involving the new product, process, system or device.

Diffusion refers to the process by which the innovation spreads across the market. All these three phases of technical change are aspects of technological capabilities and there are many attempts to measure technological capabilities at the country level. For example, the World Economic Forum (WEF) Technology Index and Technology Capacity Index developed by the RAND Corporation are indicators of technological capabilities.

In this paper, we adopt scientific publications as a measure of technological capabilities. First, data on scientific publications is an output indicator and a constituent factor in many country technology indices. Second, we prefer a measure that is associated with the production of knowledge at the invention phase of technical change. Since an invention may not be patented and does not necessarily lead to innovation, the data on scientific publications is a best reflection of the creation of knowledge. Third, data on scientific publications are collected homogeneously for all countries and from reliable sources. Fourth, , there is no possible artificial relationship between technical change and growth volatility when scientific publications, as opposed to TFP growth, is used to measure technical change. Fifth, using data on scientific publications roughly doubles the number of countries in the sample compared to country technology indices. However, the disadvantages of using scientific publications are that quality and sectoral distribution varies from country to country and that English-speaking countries are likely to be over-represented.

The second key variable of this paper is growth volatility. In the literature, a widely-used measure of growth volatility is the standard deviation of the growth rate of real GDP as in Ramey and Ramey (1995) and Martin and Rogers (2000) in their cross-country study of the interaction of business-cycle volatility and growth. However, some argue that the standard deviation of the growth rate of real GDP may not be an appropriate measure of business-cycle volatility because the underlying first difference filter removes frequencies from the data that are not normally attributed to business cycles (see, for example, Pedersen, 1998). They suggest using the standard deviation of trend deviations as measure of business-cycle volatility. Blanchard and Simon (2000) report that their results on the sources of the decline of output volatility in the US are not much affected by choosing standard deviations of either growth rates or trend deviations as a measure of business-cycle volatility. In this paper, we use both the standard deviation of growth rates and trend deviations in our analysis to check for consistence of our results. Appendix B describes the construction and sources of this and the other key variables in more detail.

4. Technical Change and Growth Volatility

4.1 Scientific and Technical Publications

To begin, we look at the correlation between growth volatility and (lagged) technical change measured by, respectively, the standard deviations of per capita real GDP growth rates and scientific and technical publications. The unbalanced panel dataset includes 145 countries and 429 observations for the five-year periods of 1980-84, 85-89, 90-94, and 95-99. The panel is unbalanced because some countries do not have data on scientific and technical publications for all four time periods in the panel.

The simple regression result between the standard deviation of growth (σ_{it}) and the (log) number of scientific and technical publications lagged one period ($Sci_{i,t-1}$) is

$$\sigma_{i,t} = 5.582 - 0.418\left(\mathrm{Sci}_{\mathrm{i,t\text{-}1}}\right)$$
$$(17.7) \quad (-7.5)$$

(R^2 = 0.12, *t*-statistics in parentheses), and the result for the sample of 30 OECD countries is

$$\sigma_{i,t} = 4.582 - 0.344\left(\mathrm{Sci}_{\mathrm{i,t\text{-}1}}\right)$$
$$(9.7) \quad (-6.0)$$

(R^2 = 0.24, *t*-statistics in parentheses).

The simple regression results for both samples show a negative and statistically significant relationship between the standard deviation of growth rates and the lagged number of scientific and technical publications. The *t*-statistics for the slope coefficients are statistically significant at the one percent level. Thus, in both samples, there is evidence that countries with a higher number of scientific and technical publications tend to have systematically lower growth volatility. Figure 1 and 2 show the scatter diagrams between the two variables for the 145-country whole world sample and 30-country OECD countries. We can see a clear negative best-fitted line across the observations in both figures. The figures show clearly that the negative relationship between the number of scientific and technical publications and growth volatility is not induced by a few outliers.

Figure 1: Simple Correlation of Growth Volatility and Technical Change: World

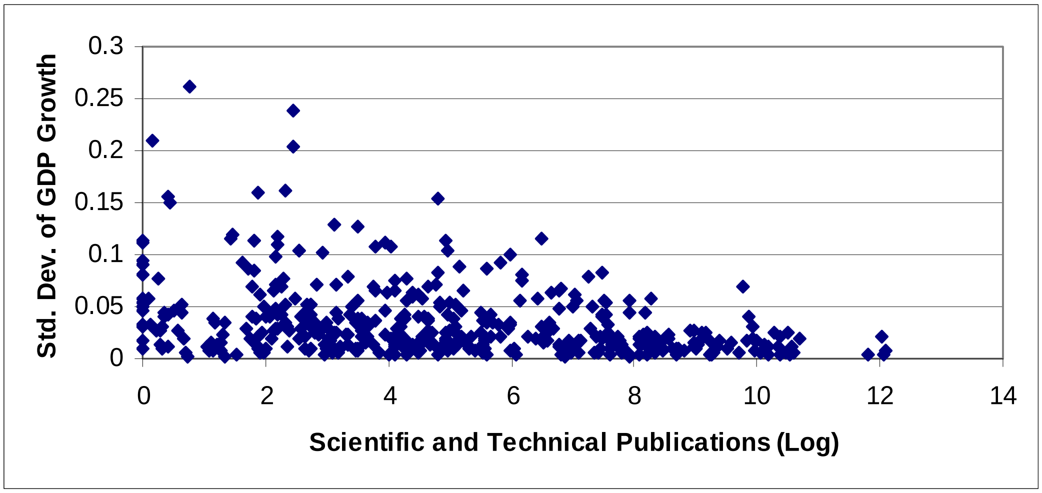
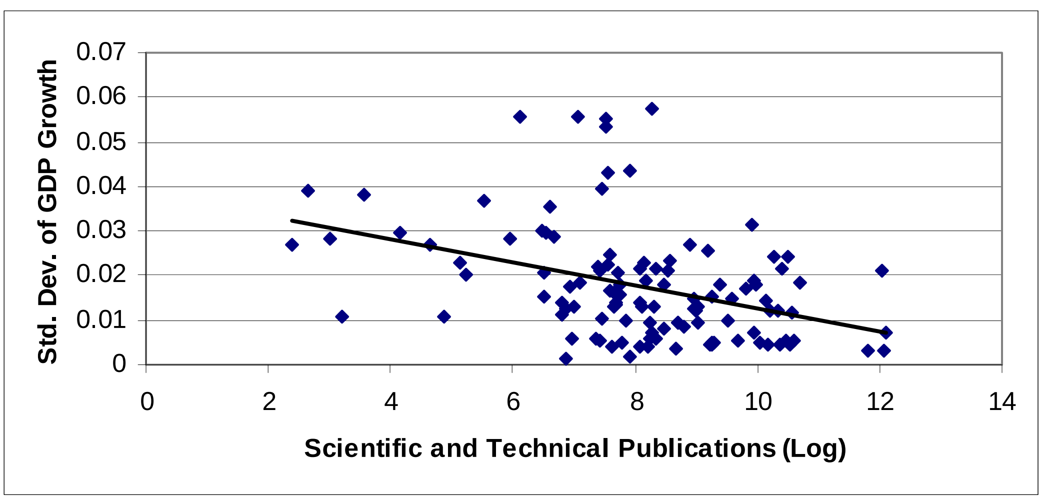


Figure 2: Simple Correlation of Growth Volatility and Technical Change: OECD



We next examine the relationship between growth volatility and technical change by controlling for the effects of important characteristics of the sample countries over time. The econometric model is

(1) $$\sigma_{i,t} = \beta_1(Sci_{i,t-1}) + \theta X_{i,t-1} + a_i + u_{it}$$

where the subscripts *i* and *t* are country and time indexes, σ_{it} is the standard deviation of annual per capita real growth rates and $Sci_{i,t-1}$ is the lagged number of scientific and technical publications in logarithmic. θ is a vector of coefficients. $X_{i,t-1}$ is a vector of control variables which varies over time, a_i is a vector of unobserved fixed country- and time-effects, and u_{it} is an idiosyncratic error. The key parameter of interest is β_1, which links technical change to growth volatility.

We include in $X_{i,t-1}$ the log of initial income per capita as a key control variable. This variable is usually included in growth regressions to control for convergence effects, but it is also useful to include it in the volatility regressions because according to Acemoglu and Zilibotti (1997) poorer countries suffer substantially more volatility. Another control variable is the growth rate of population. Since the effect of the average population growth in a given country is already controlled for with the unobserved country-fixed effects, the coefficient of this variable captures the volatility effects of abnormal population growth. We estimate Model 1 by using OLS with dummy variables to control for the vector of unobserved country- and time-fixed effects, a_i. Furthermore, all the explanatory variables are lagged one period to avoid the possibility of reverse causality.

The key results of panel data fixed effects regressions are reported in Table 1. Column (1) and (2) are results from the whole world sample of 145 countries, while Column (5) and (6) are those generated from the sample of 30 OECD countries. The estimated coefficient $\widehat{\beta}_1$ in Column (1) is -0.491, which is statistically significant at the one percent level against a one-sided alternative. The results of a negative and highly statistically significant estimate for research publications in Column (1) provides further evidence that countries with a higher level of technical change tend to have lower growth volatility even after controlling for unobserved country- and time-fixed effects. The strength of $\widehat{\beta}_1$ increases from –0.418 in the simplest OLS regression without controlling for any fixed effects to –0.491 in Table 1, Column (1), where the full set of unobserved country- and time-fixed effects is added, indicating that the estimated effect of technical change on growth volatility becomes more pronounced when we add more control variables in the regression.

In Table 1, Column (2), we add the time-varying control variables of initial income and population growth in the regression of the whole world sample. The results show that the level of technical change as measured by the (log) number of scientific and technical publications lagged one period continues to be a statistically significant explanatory variable of growth volatility at the 1 percent level. The estimated coefficient, $\widehat{\beta}_1$, is -0.474, which predicts a reduction of 0.474 standard deviation of annual per capita growth rates for every one percent increase in the number of scientific and technical publications. Thus, the stabilizing effect of technical change is both economically and statistically significant.

Table 1: Fixed Effects Panel Data Regressions of Growth Volatility

	Whole world		OECD	
	(1)	(2)	(3)	(4)
Research output	-0.491[a] (-2.534)	-0.474[a] (-2.398)	-0.730[a] (-4.804)	-0.744[a] (-6.347)
Initial income		3.010[b] (1.830)		1.876 (1.628)
Pop. growth		-0.800 (-1.563)		-0.529 (-1.198)
85-89	0.555[a] (2.378)	0.001 (0.004)	1.065[a] (4.583)	0.749[a] (2.427)
90-94	-0.269 (-1.149)	-0.883[b] (-1.947)	-0.321 (-1.465)	-0.634[b] (-1.846)
95-99	-0.596[b] (-2.243)	-1.526[a] (-2.660)	-0.297 (-1.441)	-0.835[b] (-2.187)
No. of obs.	429	429	115	115
No. of countries	145	145	30	30
R-sq. adj.	0.446	0.464	0.482	0.485

Notes:
1. All regressions include unreported country fixed effects.
2. The dependent variable is standard deviations of growth rates of real GDP per capita.
3. Numbers in parentheses are heteroskedasticity-robust *t*-statistics.
4. [a] is significant at the 1% level and [b] the 5% level against a one-sided alterative.
5. See Appendix B for definitions and sources of data.

In Table 1, Column (2), we find that initial income is positively and significantly related to growth volatility after accounting for the level of technical change, population growth and other country- and time-fixed effects. There is thus some evidence to support the claim that a higher income per sec, without the benefit of technical change, has a destabilizing effect on growth.[3] This result, however, is not robust across all samples. The estimate for population growth rate is negative but insignificant, indicating the effects of population growth on growth volatility have been fully accounted for in the country- and time-fixed effects.

We also present the estimates for the time-fixed effects in Table 1, Column (1) and (2).[4] The estimated unobserved time-fixed effects for the periods 1990-94 and 1995-99 are all negative and mostly significant at the conventional levels, reflecting the substantial reduction in growth volatility in the 1990s compared to the base period of 1980-84. On the contrary, the estimated unobserved time-fixed effect for the period 1985-89 indicates that growth is much more volatile in this period compared to the base period of 1980-84, possibly owing to the severe recession affecting the world in 1985.

Estimated results from the sample of 30 OECD countries shown in Table 1, Column (3) and (4) resemble those of Column (1) and (2), except that the strength and significance of the estimated effects of technical change on growth volatility are much larger. The strength of $\widehat{\beta}_1$ increases from -0.344 in the simple regression without any controls to –0.730 in Table 1, Column (3) where the full set of unobserved country- and time-fixed effects is added and it is statistically significant at the one percent level. In Column (4), adding the time-varying controls of initial income and population growth increases both the strength and significance of $\widehat{\beta}_1$, while the two control variables are not statistically significant at the conventional levels. If the observed negative link between technical change and growth volatility is due mainly to the difference in the income level between wealthier and poorer countries, then we should not expect to observe such a link among the relative homogenous OECD countries. We, however, observe a much stronger link among the OECD countries. Thus, results from the OECD sample in Column (3) and

[3] This result appears to complement studies arguing that growth and growth volatility are positively related (see, among others, Black, 1987).
[4] Estimates for the unobserved country-fixed effects are not presented in Table 1 due to space constraint.

(4) further show that the observed negative link between technical change and growth volatility is not driven by the difference in the income level between wealthier and poorer countries.

Estimates of unobserved time-fixed effects for the OECD sample in Column (3) and (4) are consistent with those of the whole world sample in Column (1) and (2). The periods 90-94 and 95-99 are marked by significant reduction in growth volatility, whereas the period 85-89 is marked by significant increase in volatility compared to the base period of 80-84.

4.2 Alternative measures of technical change and growth volatility

How robust is the negative link between technical change and growth volatility? Can it survive alternative measures of technical change and growth volatility? Rather than using the number of scientific and technical publications for a measure of technical change and the standard deviation of GDP growth for a measure of growth volatility, we test our hypothesis by using alternative measures of technical change and growth volatility in this section.

In the literature, the most widely-used proxy of technical change is the Solow's residual or TFP growth. We obtain TFP growth by adopting the non-parametric growth accounting approach. There is a smaller number of countries in this sample (87 countries) compared to the sample of scientific and technical publications (145 countries) due primarily to the unavailability of reliable data on capital stock for many countries for the calculation of TFP growth. We, however, have a longer sample period starting from 1965 to 1990, which is divided into five periods (65-69, 70-74, 75-79, 80-84, and 85-89). We also measure growth volatility differently; Growth volatility is measured not by the standard deviation of per capita GDP growth, but by the standard deviation of trend deviations estimated from an autoregressive model of GDP growth.[5] We relegate the detail of obtaining TFP growth and the standard deviation of trend deviations to Appendix B.

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[5] The procedure for generating the standard deviation of output shocks is similar to Blandard and Simon (2001).

We have an unbalanced panel of 87 countries and 432 observations for this sample. Result of the simple OLS regression between the standard deviation of trend deviations (σ_{it}) and lagged TFP growth ($TFP_{i,t-1}$) is

$$\sigma_{i,t} = 2.861 \text{ - } 5.069\left(TFP_{\text{i,t-1}}\right)$$
$$(18.2) \quad (\text{-}2.9)$$

(R^2 = 0.02, *t*-statistics in parentheses), and the result for the sample of 24 OECD countries is

$$\sigma_{i,t} = 1.5169 \text{ - } 15.570\left(TFP_{\text{i,t-1}}\right)$$
$$(16.0) \quad (\text{-}2.3)$$

(R^2 = 0.04, *t*-statistics in parentheses).

The results of simple OLS regressions for both the 87-countries whole world sample and 24 OECD countries show that technical change when measured by TFP growth has a significant negative link with growth volatility which is measured by the standard deviation of trend deviations. The statistical significance is at one percent level against a one-sided alternative for the whole world sample. We plot (lagged) TFP growth against the standard deviation of trend deviations for both samples in Figure 3 and Figure 4. In both scatter plots, we see a clear negative link between TFP growth and the standard deviation of trend deviations which are not induced by few outliers.

Figure 3: Simple Correlation of the Standard Deviation of Trend Deviations and TFP Growth: World

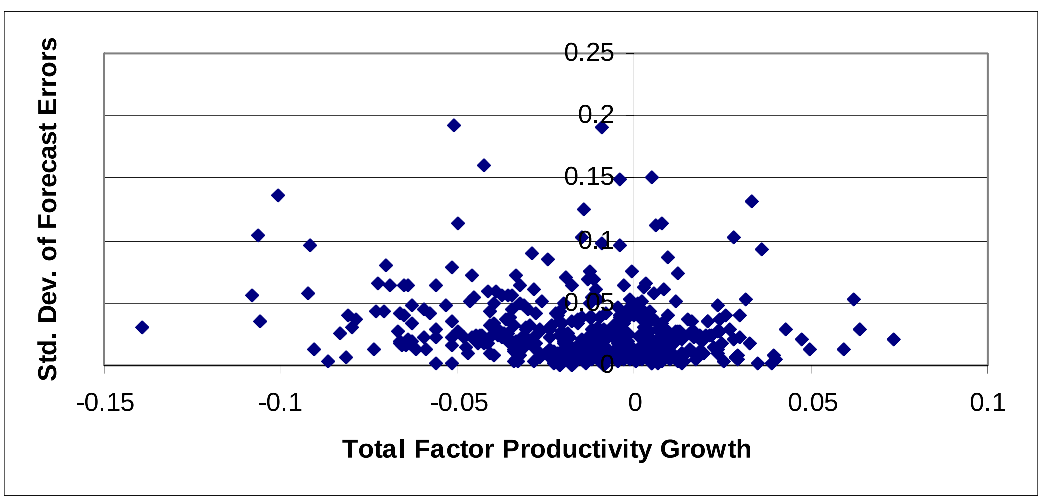
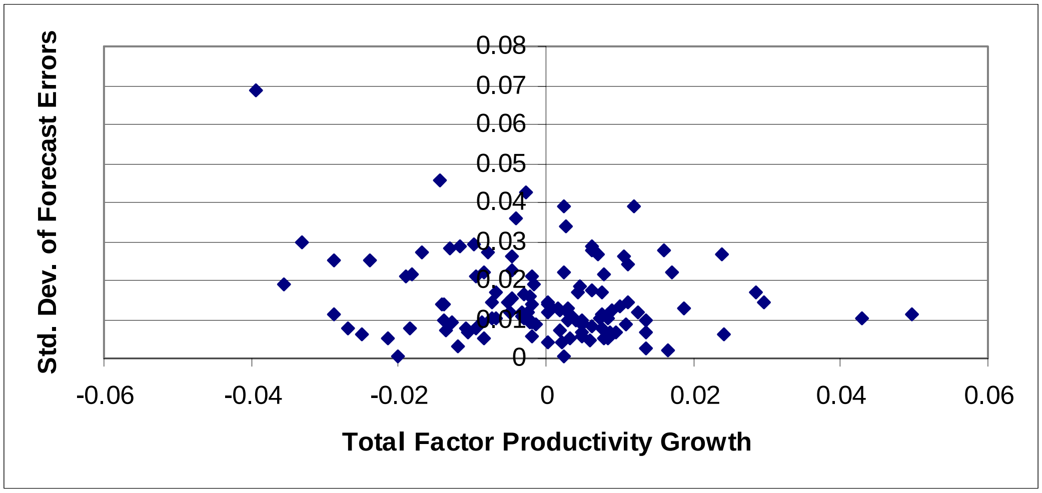


Figure 4: Simple Correlation of the Standard Deviation of Trend Deviations and TFP Growth: OECD



Next, we add both time-varying control variables and time-invariant country- and time dummies to control for unobserved effects across countries and over time in the regressions. The results of fixed effect regressions using (lagged) TFP growth and standard deviation of trend deviations are presented in Table 2. Column (1) and (2) are results of the whole world sample and (3) and (4) are results of the OECD sample. The dependent variable is the standard deviation of trend deviations and the key parameter of interest is β, the coefficient of TFP growth. Column (1) indicates that after accounting for unobserved country- and time-fixed effects, technical change as measured by TFP growth has a negative and significant link to growth volatility at the five percent level. Adding time-varying control variables of initial income and population growth strengthen the magnitude and significance of $\widehat{\beta}$ in Column (2). It is also interesting to note that in Column (2) population growth is negatively link to growth volatility and this link is statistically significant at the five percent level. We interpret the result that faster population growth could reflect an improvement in the quality of human capital which in turn tends to stabilize growth. In both Column (1) and (2), estimated time effects indicate, as expected, that growth is significantly more volatile in the 1970s and 1980s compared to the based period of 1960s.

In Table 2, Column (3) and (4), we present results of the OECD sample. $\hat{\beta}$ continues to be negative and statistically significant at the conventional levels. The magnitude and significance of $\hat{\beta}$ increase substantially from Column (1) and (2) to (3) and (4), suggesting that the impact of technical change on growth volatility is much greater in the case of wealthier OECD countries. We interpret this result as a good indication of high-tech technology is more efficient (or flexible) in absorbing output shocks than that of the low-tech technology. Once again, the results of the OECD sample in Table 2, Column (3) and (4) show that there is a statistically significant negative link between technical change and growth volatility, which cannot be attributed to the difference in income level between the wealthier and poorer countries.

Table 2: Fixed Effects Panel Data Regressions of Growth Volatility

	Whole world		OECD	
	(1)	(2)	(3)	(4)
TFP Growth	-2.874[b] (-1.757)	-3.405[b] (-2.028)	-17.326[b] (-2.232)	-17.163[b] (-2.281)
Initial income		-0.944 (-0.959)		-0.613 (-0.753)
Pop. Growth		-1.017[b] (-2.091)		-0.572[b] (-1.910)
70-74	1.944[a] (4.834)	2.019[a] (4.829)	0.653[a] (2.353)	1.003[a] (3.055)
75-79	1.062[a] (3.673)	1.229[a] (3.060)	0.322 (1.220)	0.615 (1.532)
80-84	1.655[a] (3.919)	1.896[a] (2.992)	0.454 (1.424)	0.754 (1.595)
85-89	1.025[a] (3.545)	1.110[b] (2.199)	0.328 (1.340)	0.632 (1.121)
No. of obs.	432	421	118	112
No. of countries	87	85	24	23
R-sq. adj.	0.202	0.221	0.014	0.093

Notes:

1. All regressions include unreported country fixed effects.
2. The dependent variable is standard deviations of trend deviations.
3. Numbers in parentheses are heteroskedasticity-robust *t*-statistics.
4. [a] is significant at the 1% level and [b] the 5% level against a one-sided alterative.
5. See Appendix B for definitions and sources of data.

In sum, we have shown clearly a negative link between technical change and growth volatility in this section. This link survives the addition of a host of control variables including the initial income level, population growth and a full set of unobserved country- and time-fixed effects. More importantly, we show that there is an even stronger negative link between technical change and growth volatility among the wealthier, relatively homogenous OECD countries. Moreover, the link survives alternative measures of technical change and growth volatility. No matter how technical change is measured by the number of scientific and technical publications or by TFP growth, we observe its impact on growth volatility is still significantly negative, regardless whether growth volatility is measured by the standard deviation of GDP growth or the standard deviation of trend deviations.

5. A Test of Endogeneity Between Technical Change and Growth Volatility

In the last section, we show that there is a significant negative link between technical change and growth volatility that is unlikely due to specification error, sampling bias or mis-measurement of the key variables. However, there is still one lingering worry: the observed link can be the result of reverse causality. That is, the observed link between technical change and growth volatility is driven by growth volatility rather than by technical change. Under this scenario, countries with more stable growth experience a higher level of technical change. Although there are economic rationales to justify the reverse causality, we do not expect that it is the driving force of the observed link between technical change and growth volatility in our sample despite we have used lagged technical change to avoid such a problem. Consequently, we derive a test to check the validity of the claim that technical change is the driving force of growth volatility and not the other way around.

The logic of this simple test is similar to the Granger causality test. We argue that if technical change is the driving force of the link between technical change and growth volatility, then we should expect that countries with a higher level of technical change 20 years ago exhibit a more stable growth 20 years later, after controlling for their income level. On the contrary, if growth volatility is the driving force of the link, then we should expect that countries with more stable growth 20 years ago exhibit a higher level of technical change 30 years later, after controlling for their income level. Of course, it is possible that both technical change and growth volatility are the driving forces of each other or none of them are driving forces of each other.

We implement the test by regressing the standard deviation of GDP growth of the last sample period on the number of scientific and technical publications of the first sample period. The results are presented in Table 3, Column (1). As expected, the level of technical change in the first sample period is a statistically significant predictor of growth volatility more than 20 years later, after accounting for the income level. In Column (2), we present results of regressions using the standard deviation of GDP growth of the first sample period to explain the number of scientific and technical publications of the last sample period. The estimated coefficient for the standard deviation of GDP growth is -0.391, which is not statistically significant at any conventional levels although its negative sign is consistent with our expectations. Clearly, there is little evidence to suggest that the observed negative link between technical change and growth volatility in the sample is driven by the reserve causality of growth volatility feeding back to technical change.

Table 3: Tests of Endogeneity between Growth Volatility and Technical Change

	1995-99 Std. dev. of GDP growth (1)	1995-99 Research output (2)
1980-84 Std. dev. of GDP growth		-0.391 (-1.556)
1980-84 Research output	-0.369^{a} (-2.338)	
Initial income	-0.774^{b} (1.952)	0.031 (0.070)
No. of observations	37	37
R-square adjusted	0.202	0.030

Notes:

1. All regressions include an unreported constant term.
2. ^{a} is significant at the 1% level and ^{b} the 5% level against a one-sided alterative.
3. See Appendix B for definitions and sources of data.

6. A Deeper Determinant of Growth Volatility?

A current debate in the growth literature is whether institutions matters for the level of long-run income and growth. Many empirical studies recently have found that strong institutional quality, in particular, property rights institutions, has an important positive effect on the long-run level of income and growth.[6] We take up this theme in this section by investigating whether institutions is a deeper determinant of growth volatility.

In order to study the independent effect of institutions on growth volatility as well as its indirect effect through technical change, we formulate an econometric model as:

(2) $$\sigma_{i,t} = \lambda \cdot INST_{i,t-1} + \beta \cdot Sci_{i,t-1} + \delta \cdot C_{i,t-1} + a_i + \varepsilon_{i,t}$$

where the subscripts *i* and *t* are country and time indexes and σ_{it} is growth volatility measured by the standard deviation of real GDP growth rates at the current time period. $INST_{i,t-1}$ is institutions for country *i* measured at the beginning of the last time period. Institutions refer to property rights institutions, which is measured by constraint on the executive from Polity III dataset. Unlike other measures of property rights institutions such as expropriation risk from International Country Risk Guide, executive constraint is a preferred measure because it, according to North (1981), reflects a set of durable rules, procedures or norms that is designed to constrain the behavior of the policy-makers. Also, property rights institutions have the advantage of emphasizing the close linkage between property rights institutions and politics. $Sci_{i,t-1}$ is technical change measured by the lagged number of scientific and technical publications. $C_{i,t-1}$ is a vector of lagged control variables, a_i is a vector of unobserved country- and time-fixed effects, and $\varepsilon_{i,t}$ is an idiosyncratic error.

The econometric model in 2 is utilized to evaluate the link between property rights institutions, technical change and growth volatility. First, we check whether there is a strong link between property rights institutions and growth volatility by regressing σ_{it} on

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[6] For a brief summary of the debate, see Glaeser, La Porta, Lopez-de-Silanes and Shleifer (2004). Acemoglu, Johnson and Robinson (2001) show the causal effect of the institutional quality on current income level and Acemoglu and Johnson (2003) show the effect of property rights institutions and contracting institutions on growth.

$INST_{i,t-1}$ alone. The theory expects the estimated coefficient of $INST_{i,t-1}$, $\hat{\lambda}$, to be significant and negative. Second, technical change, $Sci_{i,t-1}$, is introduced as an additional explanatory variable in the regression. If technical change is a major mediating channel of property rights institutions in affecting growth volatility, adding technical change to the regression should render the estimated coefficient of $INST_{i,t-1}$, $\hat{\lambda}$, to become statistically insignificant while the estimated coefficient of $Sci_{i,t-1}$, $\hat{\beta}$, to be statistically significant. If $\hat{\lambda}$ is significant but $\hat{\beta}$ insignificant, then property rights institutions have independent effects on growth volatility and technical change is not a mediating channel for property rights institutions. If both $\hat{\lambda}$ and $\hat{\beta}$ are statistically significant after the addition of $Sci_{i,t-1}$ in the regression, then some effects of property rights institutions may still channel through technical change, yet institutions have an independent effect on growth volatility.

Regression results for Model 2 are presented in Table 4. Column (1) shows that property rights institutions alone have a statistically significant effect on growth volatility, as indicated by the *t*-ratio of -2.603 for $\hat{\lambda}$. We interpret this result as a strong indication of the stabilizing effect of property rights institutions on the economy. If we add initial income and population growth in addition to unobserved country- and time-fixed effects in Column (2), we find the effect of property rights institutions on growth volatility increases, as shown by the increase in the magnitude and significance of $\hat{\lambda}$ (-0.244 with a *t*-ratio of -2.763). The result shows again that increasing property rights institutions tend to reduce growth volatility after controlling for the income level, population growth and unobserved country- and time-fixed effects. Column (3) repeats the regression of Column (2), Table 1, where we regress the standard deviation of growth rates on the lagged number of scientific and technical publications. Once again, technical change is a statistically significant explanatory variable of growth volatility at the conventional significance levels. Also, both regressions have very similar estimated results despite using different samples of the original dataset (the sample in this section has 389 observations rather than 429 observations due to unavailability of executive constraint). This further illustrates the robustness of the link between technical change and growth volatility.

Table 4: Deeper Determinant of Growth Volatility: Property Rights Institutions

	Standard deviation of growth rates			
	(1)	(2)	(3)	(4)
Initial executive constraint	-0.219[a] (-2.603)	-0.244[a] (-2.763)		-0.218[a] (-2.455)
Research output			-0.448[b] (-2.300)	-0.399[b] (-2.047)
Initial income		3.408[b] (2.039)	3.261[b] (1.944)	3.225[b] (1.913)
Pop. Growth		-0.768 (-1.449)	-0.745 (-1.359)	-0.806 (-1.503)
85-89	0.292 (1.148)	-0.335 (-1.042)	-0.140 (-0.437)	-0.160 (-0.494)
90-94	-0.494[b] (-2.095)	-1.156[a] (-2.571)	-0.948[b] (-2.054)	-0.862[b] (-1.828)
94-99	-0.668[a] (-2.492)	-1.646[a] (-2.854)	-1.504[a] (-2.582)	-1.320[b] (-2.200)
No. of obs.	398	398	398	398
No. of countries	134	134	134	134
R-sq. adj.	0.466	0.487	0.486	0.490

Notes:

1. All regressions include unreported country- and time-fixed effects.
2. The dependent variable is standard deviations of growth rates of real GDP per capita.
3. Numbers in parentheses are heteroskedasticity-robust *t*-statistics.
4. [a] is significant at the 1% level and [b] the 5% level against a one-sided alterative.
5. See Appendix B for definitions and sources of data.

In Column (4), we add scientific research output to property rights institutions and other control variables in the regression. The results show that both property rights institutions and scientific research publications are statistically significant at the conventional levels. Also, the magnitude and significance of $\hat{\lambda}$ become slightly smaller in the presence of scientific research output in the regression. Thus, while property rights institutions have an independent effect on growth volatility, there appear some modest effects of property rights institutions channeling through technical change.

This section intends to evaluate the role of property rights institutions in affecting growth volatility either independently or through technical change or both. First, we find that property rights institutions have a statistically significant independent effect on growth volatility when it is measured by executive constraint, a conceptually superior and preferred measure of property rights institutions. This result is consistent with the literature (such as Sah, 1991). Some of the effects of property rights institutions on growth volatility also channel through technical change because adding technical change (scientific publications) in the regression reduces both the magnitude and significance of $\hat{\lambda}$. Thus, the results of this section clearly indicate that technical change does not operate alone in vacuum to affect growth volatility. Property rights institutions are an important independent source of effect as well as working through technical change to affect growth volatility.

7. Conclusions

There seems to be a general misconception that technological innovations necessarily lead to volatile growth. Many believe that the bust and boom of business cycle fluctuations are caused by the successes and failures of technological innovations. In this paper, we uncover the stabilizing effect of technical change. With a higher level of technical change measured either by the number of scientific or technical research publications or TFP growth, a country is able to lower its growth volatility measured either by the standard deviation of GDP growth or the standard deviation of trend deviations. This link, we find, is a robust one: a one that is not due to a few outliers, reverse causality or mis-measurements of key variables. More importantly, this link is observed independent of the income level of the countries. Regardless it is the 145-country whole world sample or the wealthier 30-coutnry OECD sample, the negative link between technical change and growth volatility is nevertheless observed.

We also explore the possibility that property rights institutions are a deeper determinant of growth volatility by evaluating their direct and indirect effect through technical change. Our results show that property rights institutions, when is measured by constraint on executive, have independent effects on growth volatility. On average, increasing the quality of property rights institutions reduces growth volatility directly. In addition, we also observe some modest indirect effects of property rights institutions channeling through technical change. All in all, the results suggest a strong role played by property rights institutions in affecting growth volatility either independently or via its effects on technical change.

This paper evaluates the link between technical change and growth volatility without attempting to disentangle the complex relationship between the two variables. The question to be answered is why we observe such a link between growth volatility and technical change. A highly stylized framework proposed in the beginning of the paper gives a partial story: A higher level of technical change allows for the production of a variety of high value-added goods and services, improved stabilization policies and growth of financial systems, which are believed to reduce growth volatility. Much more work is to be done to ascertain the exact nature of these and other channels between technical change and growth volatility in the future.

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Appendix A: List of the 144 Countries in the Sample (Including 30 OECD Countries)

Country	*SD*	*RO*	*Country*	*SD*	*RO*	*Country*	*SD*	*RO*
Albania	6.43	10	Iran	2.18	175	Vietnam	4.20	57
Algeria	1.41	106	Israel	1.84	4637	Yemen,	9.20	8
Angola	10.85	1	Jamaica	1.53	61	Zambia	3.32	33
Antigua & Barbuda	5.26	0	Jordan	2.89	148	Zimbabwe	5.93	107
Argentina	5.75	1432	Kazakhstan	6.71	172			
Armenia	3.27	164	Kenya	1.63	265	***OECD***	***SD***	***RO***
Azerbaijan	6.36	139	Latvia	2.85	156	Australia	1.51	10047
Bangladesh	0.96	123	Lebanon	5.23	59	Austria	0.96	2622
Barbados	2.98	17	Lesotho	5.40	4	Belgium	5.28	15659
Belarus	6.71	626	Lithuania	5.21	168	Canada	1.80	19354
Belize	2.54	1	Macedonia	1.95	32	Czech Republic	3.37	1313
Benin	2.32	9	Malawi	8.05	29	Denmark	1.43	3595
Bolivia	0.70	17	Malaysia	2.00	264	Finland	2.01	2976
Botswana	1.78	23	Mali	4.90	10	France	1.13	22205
Brazil	3.04	2344	Malta	4.90	11	Germany	1.16	30860
Bulgaria	7.12	2817	Mauritius	1.95	5	Greece	1.42	1400
Burkina Faso	2.54	15	Moldova	5.67	139	Hungary	2.46	1807
Burundi	9.97	8	Morocco	7.00	158	Iceland	2.63	82
Cambodia	2.39	2	Mozambique	5.40	8	Ireland	2.29	858
Cameroon	1.81	50	Namibia	4.03	8	Italy	1.14	12050
Cape Verde	3.25	0	Nepal	2.00	24	Japan	1.65	35028
CAR	11.42	7	Nicaragua	4.08	7	Korea, Rep.	4.21	1627
Chad	6.41	1	Niger	1.53	17	Luxembourg	2.62	17
China	2.66	4409	Nigeria	6.78	664	Mexico	3.41	1116
Colombia	1.36	129	Pakistan	1.42	233	Netherlands	0.79	8805
Comoros	6.14	0	Panama	1.91	34	New Zealand	2.18	1994
Congo, Dem.	8.20	28	PNG	6.09	45	Norway	1.27	2256
Congo, Rep.	5.36	12	Paraguay	2.28	6	Poland	2.20	3979
Costa Rica	2.69	58	Peru	3.84	62	Portugal	1.90	551
Cote d'Ivoire	2.35	35	Philippines	2.87	140	Slovak Republic	2.98	526
Croatia	1.82	514	Romania	5.82	561	Spain	2.93	6471
Cuba	3.96	89	Russian Fed.	5.63	12294	Sweden	1.30	7315
Cyprus	7.18	16	Rwanda	13.98	9	Switzerland	1.49	5709
Dominica	3.74	0	Senegal	5.34	0	Turkey	3.68	889
Dominican	2.97	7	Seychelles	0.94	66	United Kingdom	1.16	36104
Ecuador	2.42	22	Sierra Leone	8.29	9	United States	0.86	163495
Egypt	1.20	1144	Singapore	3.55	406			
El Salvador	1.62	3	Slovenia	2.84	278			
Equatorial Guinea	31.02	1	South Africa	1.46	2144			
Estonia	2.71	197	Sri Lanka	2.61	78			
Ethiopia	6.00	77	St. Kitts & Nevis	3.77	0			
Fiji	4.25	15	St. Lucia	4.38	1			
Gabon	2.42	14	St. Vin. & Grenadine	6.43	0			
Gambia	5.76	22	Swaziland	1.37	5			
Georgia	15.4	123	Tajikistan	4.32	28			
Ghana	3.02	51	Tanzania	6.00	81			
Grenada	1.81	0	Thailand	4.93	291			
Guatemala	1.07	20	Togo	5.59	5			
Guinea	0.97	2	Trinidad & Tobago	9.47	45			
Guyana	8.01	5	Tunisia	1.58	119			
Haiti	11.66	3	Uganda	1.48	29			
Honduras	2.87	5	Ukraine	4.94	1719			
Hong Kong	3.65	765	Uruguay	3.85	69			
India	1.84	9719	Uzbekistan	8.71	273			
Indonesia	3.67	95	Venezuela	3.02	347			

Appendix B: Data and Sources

1. Growth volatility: Volatility is measured by the standard deviation of annual real GDP per capita growth rate for the sample periods. Alternatively, growth volatility is measured by the standard deviation of the error term from an autoregressive model of the annual GDP per capita growth rate. That is, $G\dot{D}P_t = a_0 + a_1 G\dot{D}P_{t-1} + a_2 G\dot{D}P_{t-2} + a_3 G\dot{D}P_{t-3} + \varepsilon$. We use an AR(3) model since each sub-period has only 5 years. We estimate this equation for all five sub-periods over 1965-90 in each country.
2. Growth: Annual real GDP per capita growth rates for the sample periods are calculated from RGDPCH in *Penn World Table 6.1*.
3. Initial constraint on executive: It measures the institutional and other constraints that are placed on presidents and dictators. It has a scale from 1 to 7, with higher scores indicating more constraints. Score of 1 indicates unlimited authority; score of 3 indicates slight to moderate limitations; score of 5 indicates substantial limitations; score of 7 indicates executive parity or subordination. Scores of 2, 4 and 6 indicate intermediate values. Data are available from *Polity III* dataset compiled by Keith Jaggers and Ted Robert Gurr, 1996, Inter-University Consortium for Political and Social Research.
4. Log initial GDP per capita: Natural logarithm of real GDP per capita at the beginning of the sample period. Data are from *Penn World Table Mark 6.1* (RGDPL, Laspeyres index).
5. Population growth: Annual growth rate of population taken from *Penn World Table 6.1*.
6. Scientific and technical publications: Number of journal articles published in scientific and technical journals from *World Development Table* CDROM 2000.
7. TFP growth: A measure of technical change is derived from a non-parametric growth accounting framework that resembles Collins and Bosworth (1996). TFP growth for each country is calculated by:

   (A.1) $$a = \Delta y_t - \alpha \Delta K_t + (1-\alpha)\Delta L_t$$

   where Δy_t, ΔL_t and ΔK_t represent the growth of output, growth of physical capital and growth of labor, respectively, at each time period, t. The term in Equation (A.1), a, represents the growth rate of TFP. The weight in Equation (A.1), α, represents the share of income earned by capital in a competitive economy, and as in the study of Collins and Bosworth (1996), we use a uniform capital share of 0.35 for the entire 98 sample countries.