The Link between Institutions, Technical Change and Macroeconomic Volatility

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Abstract:
This paper evaluates the role of technical change as a mediating channel through which the effects of institutions trickle down to affect growth volatility. Using different samples, estimation procedures and indicators of institutions and technical change, the results show that technical change is an important stabilizing force of growth volatility and that at least part of the stabilizing force of technical change originates from strong institutions. This conclusion does not appear to be generated by weak data, simultaneity bias or measurement errors and is remarkably robust to a large number of alternative specifications.

Keywords: Institutions, Technical change, Growth volatility, Economic growth

JEL classifications: O11, O33, E32 , O57

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1. Introduction

Economic growth is highly volatile over time. Developing countries, in particular, have experienced dramatic growth fluctuations and reversals throughout their development. For example, the recent Asian financial crisis of 1997 serves as a vivid reminder of the fragility of some developing countries. Thailand, for example, fell from an average annual growth rate of 7.5 percent before 1997 to -10.2 percent in 1998. During the postwar period from 1950 to 2000, the standard deviation of annual GDP growth rates for the poorest quartile of 154 countries averaged 7.3 percent, while the same figure for the richest quartile was 3.9 percent.[1] The magnitudes of the swings in growth of the poorest counties are almost twice those of the richest countries. What contributes to the enormous growth fluctuations of these countries?

The institutional school provides a fundamental rationale of macroeconomic volatility.[2] It blames weak institutional quality such as ineffective rule of law and little restrictions on executive power for high macroeconomic volatility. Many studies in the area support the positive role of institutions on reducing macroeconomic volatility.[3] However, few studies have been able to identify the main mediating channels through which institutional quality asserts itself. A study by Acemoglu, Johnson, Robinson and Thaicharoen (2003) (henceforth, AJRT) finds that there is a strong link between institutions and growth volatility and that neither standard macroeconomic variables nor political crises are the mediating channels through which institutions affect volatility.

This paper asks whether technical change is an important stabilizing force of macroeconomic volatility and whether at least part of the stabilizing force of technical change originates from strong institutions. The first link is between institutions and technical change, which is based on the "stylized fact" that institutional weaknesses increase uncertainty and undermine the incentives for the accumulation of both physical

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[1] The mean growth rate over the same period for the poorest quartile of countries is approximately 0.9 percent and for the richest quartile is 2.9 percent. Thus, the growth rate for the poorest countries is three times lower and twice more variable as the growth rate for the richest countries. Recent studies such as Easterly et al. (1993) and Pritchett (2000) also find that countries frequently experience dramatic reversals in growth, so that a country's growth in one decade is little related to growth in the next.

[2] The terms macroeconomic volatility and growth volatility are used interchangeably in this paper. See Section 2 and Appendix 1 for definitions.

[3] Among others, see Jones and Olken (2005), Almeida and Ferreira (2002), Rodrik (1999) and Sah and Stigliz (1991) for the relationship between institutions and macroeconomic volatility.

and human capital. A direct result of weak institutions is thus a reduction in a society's investment and its capacity for innovative activities and technical change.[4]

The second link is between technical change and macroeconomic volatility. We hypothesize that a country with little technological capacity is likely to experience higher macroeconomic volatility. Some arguments for this link between technical change and macroeconomic volatility can be summarized as follows:

1. Countries with little technological know-how have limited capacity to produce a variety of value-added products. Their economies tend to be heavily dependent on a single sector or even a single commodity. When there is a positive demand shock for a product of a country, the economy of that country experiences a higher growth rate than the economies of countries that are more diversified. Conversely, when an external shock such as a deterioration of terms of trade hits, countries with little technological know-how face a more severe downturn (Koren and Tenreyro, forthcoming).
2. Countries with little indigenous technological know-how rely primarily on foreign investment and technology in their drive for industrialization. It has been shown that industries that are more dependent on external finance are hit harder during recessions, especially when they operate under a poor financial system (Braun and Larrain, 2005). The uncertain nature of external finance adds to increased output volatility for countries with industries that are mostly dependent on foreign sources for capital and technical know-how.
3. If technical change is accompanied by financial development, more developed financial systems should imply a reduced impact of asymmetric information problems, as financial institutions become more capable of identifying projects with a higher probability of failure (Da Siva, 2002).

These three arguments are examples of many possible explanations of the influence of macroeconomic volatility via technical change. The primary objective of the current paper is *not* to identify each of these technological channels and assess its effects on macroeconomic volatility, but to provide empirical evidence for supporting the role of

[4] There has been ample empirical support for this link. Among others, see AJRT (2003) and Barro and Sala-I-Martin (1995).

technical change as a whole in stabilizing an economy and to show that some of these stabilizing effects of technical change on an economy originate directly from a strong institutional framework. Further studies will be required to disentangle the many linkages between technical change and macroeconomic volatility.[5]

The idea that technical change is related to macroeconomic volatility is not a new one. Koren and Tenreyro (forthcoming) provide a theory of technological diversification to explain why GDP is so much more volatility in low-incoming countries. Leung, Tang and Groenewold (2006) use a simple rent-seeking model to link growth volatility to technical progress. On the empirical side, a study by Easterly and Levine (2001) finds that total factor productivity (TFP) growth, a proxy for technical change, accounts for a substantial inter-temporal and cross-sectional variation in growth. Tang (2002) shows cross-country evidence of a link between growth volatility and TFP growth. Fogli (2003) in her comments on AJRT's paper states 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 TFP growth can be an important factor in explaining macroeconomic volatility. In line with Fogli's suggestion, this paper investigates the link from institutions to technical change and to macroeconomic volatility.

This paper is related to two different streams of research in macroeconomic volatility. One is the real-business-cycle (RBC) literature, which argues that macroeconomic volatility is caused by the waves of technological innovations. This paper differs from the RBC literature by focusing on two key factors: the long-run level of technical change, rather than the fluctuations of innovative activities, and relating long-run level of technical change to institutional quality and macroeconomic volatility (see a survey by King and Rebelo, 1999). The second related research area is the relationship between macroeconomic volatility and growth. Ramey and Ramey (1995), for example, find empirical evidence to support the idea that countries with higher output volatility have lower growth. In this paper, our focus is not on the relationship between output

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[5] Some recent studies have focused on technical change in explaining the large and long decline in output volatility in the US. See, for example, Blanchard and Simon (2001) and Stock and Watson (2002).

volatility and growth but rather on the question of how institutions determine output volatility via their impact on the level of technical change.

As a preview, our results indicate that technical change is an important stabilizing force of macroeconomic volatility and that at least part of the stabilizing force of technical change originates from strong institutions. Our various estimates show that if technical change is to increase by one percentage point, growth volatility would be reduced between one-half to three percentage points depending on the measure of institutions, the measure of technical change, the sample and the estimation technique. In summary, the weight of evidence appears to support the paper's main hypothesis that stronger institutional quality tends to accelerate technical change, which reduces macroeconomic volatility.

The remainder of this paper is organized into five sections. In the second section, we discuss the construction of datasets and present some summary statistics of the key variables in the study. The third section contains the scatter plots of institutions, technical change and growth volatility and descriptions of the Wald estimate of the return to technical change. In section four, we discuss the empirical model and various estimation strategies including cross-country OLS, instrumental variables, pooled cross-sectional and panel fixed-effects estimations. The fifth section is a discussion of the main empirical findings of this paper. The sixth section contains the summary and conclusions.

2. Data and Summary Statistics

This section contains a discussion of the measurements of three key variables used in the study: institutions, technical change and growth volatility. Second, it presents a discussion of the construction of the cross-section and balanced panel data sets.[6]

Two widely-used measures of institutional quality in the empirical literature are expropriation risk by the state and initial constraint on executive power. Expropriation risk is the risk of "output confiscation" or "forced nationalization" assessed by *International Country Risk Guide*. Risk is scaled from zero to ten, with lower scores for higher risks. Knack and Keefer (1995) find that expropriation risk is a better measure of

[6] We relegate more data details and sources to Appendixes 1 and 2. Appendix 3 provides the key data for all the sample countries.

property rights than other measures such as coups and revolutions. One difficulty of using expropriation risk is the problem of simultaneous effect of macroeconomic conditions on expropriation risk. Another difficulty is that the earliest data available in this index are for January 1984. Depending upon the data set and analyses used, the time periods analyzed vary from 1965 to 1990 and 1970 to 2000 in this study.

The initial constraint on executive power is a better measure of institutional quality than expropriation risk by the state for two reasons. First, constraint on executive power is a conceptually superior measure of institutional quality because it refers to “the extent of institutional constraints on the decision-making powers of chief executives, whether individuals or collectivities.”[7] Second, there are data available for early periods. More importantly, using initial rather than current constraint on executive power helps mitigate the simultaneity bias that may result from endogenous institutions. Given these advantages of initial constraint on executive power, we prefer it over expropriation risk as a measure of institutional quality in the paper.

Another important ingredient of this paper is the measure of technical change, which is commonly estimated by TFP growth in the literature. Despite its many shortcomings, recent studies have found that TFP growth is still an accurate measure of technical change and innovation.[8] One approach to measuring TFP growth is based on the regression of average growth of output per worker on a constant and average growth of physical capital stock per worker across countries. The constant from this regression represents the world average TFP growth, while the residual for each country represents the country’s TFP growth over and above the world average. An alternative measure of technical change, which serves as a robustness check in panel data regressions, is derived from a non-parametric growth accounting framework that resembles Collins and Bosworth (1996). We leave the details to Appendix 2.

The dependent 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

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[7] Glaeser et al. (2004) argue that initial constraints on the executive is a better measure of institutional quality because it makes the greatest attempt at measuring the political environment rather than dictatorial choices and is less affected by current macroeconomic conditions.

[8] For example, using firm level data-base, Parisi et al. (2006) find that non-innovative firms consistently show a lower TFP growth.

studies 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 a measure of business-cycle volatility. Blanchard and Simon (2001) 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 our analyses, we use both the standard deviation of growth rates and trend deviations to check for consistency within our results.

This paper uses three cross-section samples (whole world, ex-colonies and upper income ex-colonies), all of which average data over the period 1970 to 2000. It also constructs two balanced panel data sets, one for the whole world and the other for the upper-income countries, which combine the five 5-year averages of the time-series data over the period 1965 to 1990. The constructions of these datasets are discussed in turn below.

The three country samples are used for ordinary least squares (OLS) and instrumental variables (IV) econometric analysis. The first sample, consisting of up to 116 countries, includes all countries for which data are available on institutions, technical change and macroeconomic volatility for the period 1970 to 2000. This sample is therefore called the "whole world". The second sample, which is called "ex-colonies", consists of 60 countries, which are taken from Acemoglu, Johnson and Robinson (2001).[9] The second cross-country sample also contains averages data from 1970 to 2000. The third sample, the "upper income ex-colonies", consists of the 30 ex-colonies that had a GDP per capita in 1970 higher than the median 1970 GDP per capita for all 60 ex-colonies. This third sample is used to show that countries of relatively the same income levels exhibit the same causal linkage running from institutions to technical change to macroeconomic volatility.

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[9] There are 64 ex-colonies in the study of Acemoglu, Johnson and Robinson (2001), but we include only 60 of their ex-colonies in our sample due to the unavailability of TFP growth for 4 ex-colonies (Bahamas, Haiti, Sudan and Vietnam).

In this paper, we have two balanced panel datasets that are used for pooled cross-sectional and panel fixed-effects regressions. The first balanced panel dataset is the whole world sample of 93 countries for the period 1965 to1990, which we divide into five 5-year intervals (1965 to 1969, 1970 to 1974, 1975 to 1979, 1980 to 1984, 1985 to 1990) for a total of 465 observations. The second balanced panel dataset consists of the upper-income countries whose GDP per capita in 1970 was higher than the median 1970 GDP per capita for all the countries in the whole world sample. Both of these panel datasets allow us to increase substantially the degrees of freedom by incorporating variability in the time-series dimension.

Summary statistics of the key variables for the different samples are presented in Table 1. For Columns 1 to 3, we note that the sample of upper income ex-colonies exhibits the best institutional quality in terms of initial constraint on executive power and expropriation risk. This sample also shows the highest average GDP per capita growth rate and the lowest average standard deviation of GDP per capita growth rate. TFP growth, however, appears to be similar in all three samples from Columns 1 to 3. For the panel data sample in Column 4, growth volatility is measured by trend deviations and TFP growth calculated by the growth accounting approach. On average, the panel data sample shows a lower growth volatility and TFP growth, which can be attributed to different approaches of measuring these variables and/or different sample periods.

(Table 1 about here)

3. Descriptive Evidence

If better institutional quality promotes technical change, which in turn reduces growth volatility, then we should observe a link between institutions and growth volatility in the samples. To detect such a link, we first look at the data for correlations between institutions and technical change and between technical change and macroeconomic volatility. Figures 1 and 2 depict scatter plots between institutions (initial constraint on executive power) and technical change (TFP growth), and between technical change (TFP growth) and macroeconomic volatility (standard deviation of annual GDP per capita growth).

Figure 1 shows that TFP growth tends to increase as initial constraint on executive power increases, although some countries experience relatively low TFP growth with their strong initial constraint on executive power, and other countries experience relatively high TFP growth with a weak initial constraint on executive power. Figure 2 shows that the standard deviation of annual GDP growth tends to decrease as TFP growth increases. The negatively sloped trend line in Figure 2 has a better fit than the one in Figure 1.[10] Figures 1 and 2 provide a “visualization” of the link between institutions and macroeconomic volatility via technical change.

(Figure 1 and 2 about here)

In Table 2, we evaluate the return to technical change based on an application of Wald’s (1940) method of fitting straight lines. This estimator computes the return to technical change as the ratio of the difference in growth volatility by institutional quality to the difference in technical change by institutional quality. We present an estimate that compares growth volatility and technical change between countries with strong institutional quality (a maximum ranking of 7 in initial constraint) and countries with weak to moderate (rankings from 1 to 6 in initial constraint) institutional quality. This comparison is selected because strong institutional quality shows the greatest impact on technical change and growth volatility.

(Table 2 about here)

As noted earlier, poorer countries tend to experience much more growth volatility than richer countries. It is important then to control for the effects of income when we evaluate the effects of institutions and technical change on growth volatility. In Table 2, we only select those countries that have an income in 1970 above the mean income level of the whole world sample in that year. Because the effect of income on growth volatility tapers off once a country’s income reaches a relatively high level, looking at the variations in growth volatility of a group of richer countries allows us to isolate the effects of institutions and technical change on growth volatility. This is shown in Table 2.

Table 2 demonstrates that countries with a strong institutional quality (initial constraint on executive power) experience 1.82 percent lower in average standard deviation of growth and 0.94 percent higher in TFP growth than countries with a weak to moderate institutional quality. These differences, indicated in Column 3, Table 2, are

[10] An outlier, Iraq, shows a standard deviation of 22.0 percent. Excluding Iraq from the samples generally slightly affects the size of regression estimates, R^2 and t-ratio, without changing the significance of the estimates and overall regressions.

statistically significant at the conventional levels. The ratio of these two differences, -1.93, is a consistent estimate of the return to technical change provided that institutional quality is uncorrelated with growth volatility determinants other than technical change.[11] The Wald estimate shows that for every one percentage point increase in technical change, macroeconomic or growth volatility decreases by roughly two percentage points when countries maintain a strong institutional quality, as opposed to weak to moderate institutional quality.

Durbin (1954) shows that the Wald estimate is a special case of IV. In our case, the Wald estimate is equivalent to IV where a dummy variable indicating whether a country maintains a strong institutional quality is used as an instrument for technical change, and there are no covariates. In Table 2, we show that the estimated return to technical change when using IV is -3.05 percent, which indicates that for every one percentage point increase in technical change, growth volatility decreases by roughly three percentage points. The difference of approximately one percent reduction in growth volatility between the Wald estimate and IV estimate is possibly due to the endogeneity in technical change. Both estimates, however, clearly reflect that strong institutional quality is positively correlated with technical change, which in turn is negatively correlated with macroeconomic volatility. This link appears to be robust to controlling for the income level. We will subject this apparent link to many more vigorous tests in the following section.

4. Econometric Methodology

We now proceed to evaluate the effects of institutions and technical change on growth volatility more formally by using an econometric model as:

(1) $$M_{c,t} = \lambda \cdot I_{c,0} + \theta \cdot T_{c,t} + \delta \cdot C_{c,0} + \varepsilon_{c,t}$$

[11] As long as unobserved growth volatility determinants are uniformly distributed across countries with different institutional qualities, the Wald estimate is consistent. For example, the quality of leaders or the probability of waging wars is likely to be uniformly distributed across countries with different institutional qualities.

where $M_{c,t}$ denotes growth volatility for country c and period t, $I_{c,0}$ is initial institutions, $T_{c,t}$ is technical change measured by TFP growth, $C_{c,0}$ represents log initial GDP per capita and $\varepsilon_{c,t}$ is the error term. The parameters of particular interest in (1) are λ and θ, which reflect the effects of institutions and technical change.

The econometric model in (1) is used to explore the relationship between institutions, technical change and growth volatility. First, we run cross-country OLS regressions of the model using the samples of whole world, ex-colonies and upper-income ex-colonies. Second, we use IV to run two-stage least squares (2SLS) regressions of the model using the samples of ex-colonies and upper income ex-colonies. Third, we run pooled cross-sectional and panel fixed-effects estimations of the model using the balanced panel data sets. Finally, we check the robustness of the results by adding various control variables to the model in (1).

To evaluate the link between institutions, technical change and growth volatility, we first show the link between institutions and growth volatility by regressing $M_{c,t}$ on $I_{c,0}$ alone. The theory expects λ to be significant and negative for the regressions of volatility. Second, technical change, $T_{c,t}$, is introduced as an additional explanatory variable in the regressions. If technical change is a major mediating channel of institutions in affecting growth volatility, adding technical change to the regressions would render λ insignificant and θ significant. However, it is possible that both parameters are statistically significant. Under such a scenario, some effects of institutions may still channel through technical change, yet institutions have an independent effect on growth volatility. We can evaluate the extent of this by the changes in the magnitude and significance of λ after technical change is introduced to the model. Finally, we cannot conclude that technical change is a mediating channel of institutions if λ is significant but θ is insignificant after introducing technical change to the model. In this case, institutional quality affects growth volatility through other means.

An important but common difficulty needs to be overcome in this study: both institutions and technical change are potentially endogenous. Hence, OLS estimates may be inconsistent and may, therefore, not reflect causal effects.[12] To deal with the potential problem of endogeneity in institutions, we follow Acemoglu, Johnson and Robinson (2001) in using the mortality rate of European settlers as an instrumental variable for institutions. They have shown that the mortality rate of European settlers serves well as an instrument for institutions in 2SLS estimations. In addition to institutions, current technical change can be endogenous. We thus propose to use past technical change as an instrument for technical change. As will be shown in the next section, mortality rate of European settlers and past technical change appear to be satisfactory instruments because their reduced-form, first-stage regression results show that they are significantly correlated with their respective variable in directions as expected. And, more importantly, the error term in (1) displays little serial correlation, which implies it has little correlation with the instruments.

In the pooled cross-sectional and panel fixed effects regressions, we have two balanced data samples. One is the whole world sample, which contains five 5-year averages for the period 1965 to 1990 for each of the 93 countries. The second one is the upper-income sample, which contains five 5-year averages for the 46 richer countries. We first use pooled cross-sectional OLS estimation to test the link from institutional quality to growth volatility via technical change. Second, we implement country fixed-effects estimations by introducing a dummy variable for each individual country in the sample. This technique controls for all unobservable time-invariant country specific factors and is appropriate when these unobservable time-invariant factors are believed to be correlated with either institutional quality or technical change. The country fixed-effects estimations offer a stringent check on the link between institutional quality, technical change and growth volatility. However, one drawback of the panel fixed-effects estimations is that we are unable to evaluate the role of institutional quality in affecting growth volatility separately since institutional quality is essentially invariant over time, making its effect inseparable from the fixed country effects.

In pooled cross-sectional and panel fixed effects regressions, the measure of technical change is different from that used in the cross-country data regressions. We use

[12] See Murray (2005) for a discussion of the procedures to avoid bad, weak and ugly instruments in IV estimations.

a TFP growth measure calculated by the growth accounting approach rather than estimated by the cross-country estimation technique. Using a different measure of TFP growth can be useful to assess the robustness of our conclusion. We hope to assess whether the regression results from the panel data are similar to those of the cross-country regressions, despite using different measures of technical change.

We are also concerned with the possibility that the observed link between institutional quality, technical change and growth volatility is an artifact resulting from excluding variables that are important determinants of macroeconomic volatility in the model. For example, a vast literature finds that growth is negatively correlated with output volatility. If such is the case, excluding growth in the model will lead to bias and inconsistency in our estimators. Hence, we subject our baseline model in (1) to multiple alternative specifications, including variables representing different regions, geography, weather, growth, human capital and openness. In the robustness checks, the balanced panel data sets are expanded to include multiple additional regressors. We then conduct both pooled cross-sectional as well as fixed-effects estimations for the different specifications of model 1. As will be shown in the end, we find invariably that the observed link between institutional quality, technical change and growth volatility remains statistically significant and its magnitude fairly stable against different sets of control variables.

5. Econometric Evidence

This section contains the regression results of the cross-country OLS, IV, pooled cross-sectional and panel fixed-effects estimations of the baseline model. Results of robustness checks are at the end of the section. First, we show the OLS estimation results for the cross-country data in Tables 3 and 4. Second, 2SLS estimation results for the ex-colonies and upper-income ex-colonies are presented in Table 5. Third, we show the results of pooled cross-sectional estimations and panel fixed-effects estimations in Tables 6 and 7. Finally, the results of robustness checks are shown in Tables 8, 9 and 10. Note that we show not only the regression results for the whole world samples, but also for the samples of upper-income countries. As discussed before, it is important to control for the effect of income on growth volatility when we evaluate the link between institutional quality, technical change and growth volatility. Using the samples of upper-income countries and adding initial per capita income as a right-hand-side variable in all the regressions reassure us that the observed link is not due to differences in income levels.

5.1 Cross-Country OLS Results

We present the cross-country OLS regression results in Table 3 and 4. In Table 3, institutional quality is measured by initial constraint on executive power whereas in Table 4 institutional quality is measured by expropriation risk. It should be noted again that initial constraint on executive power is the preferred measure of institutions since it captures the broader definition of institutions and emphasizes institutional legacies and traditions. Also, it reduces the problem of simultaneity in institutional quality.

(Table 3 and 4 about here)

In Table 3, we run the same regressions for three different samples: the whole world, ex-colonies and upper income ex-colonies. Column 1, Table 3, gives the results of using initial constraint on executive power as the only independent variable and a sample of 116 countries. Institutional quality, as measured by initial constraint, has a significant effect on the standard deviation of GDP per capita growth rate. The estimated relationship is statistically significant at the one percent level and conforms to theoretical expectation. The estimate of -0.47 in the first column indicates that if the score of initial constraint on executive power was to increase by one (initial constraint on executive power is scaled from one to seven, with higher scores for stronger constraints), then, on average, the standard deviation of annual GDP per capita growth rate is reduced by approximately 0.5 percentage points.

Column 2, Table 3, presents OLS results generated by using both initial constraint and TFP growth as regressors. In this regression, both initial constraint and TFP growth are highly significant, but the estimated effect of initial constraint is reduced when TFP growth is added (as expected, since initial constraint and TFP growth are positively correlated). Specifically, the estimated effect of initial constraint on volatility is reduced from -0.47 to -0.38 when TFP growth is added, meaning that about 19 percent of the estimated effect of institutions on volatility is channeled through technical change.

Column 3, Table 3, presents OLS results for the regressions that add log initial GDP per capita as a control variable, as suggested by Levine and Renelt (1992) for cross-country growth equations. With the addition of log initial income, the estimated results show that initial constraint and TFP growth remain highly significant while log initial income is insignificant. We note that the estimated effect of initial constraint on growth volatility is further reduced while TFP growth remains unchanged when log initial income is added. These results suggest that some effects of institutions channel through technical change, yet institutions have an independent effect on macroeconomic volatility.

Columns 4 to 6, Table 3, repeat the same regressions as in Columns 1 to 3 for a sample of 60 ex-colonies. We note that both initial constraint and TFP growth are highly significant, and the estimated effect and statistical significance of initial constraint on growth volatility remain relatively unchanged from Column 4 to 6. This suggests that the effects of institutions on growth volatility do not appear to be channeled through technical change for the sample of ex-colonies. Similarly, for the sample of ex-colonies that have an above median income in 1970, the results in Columns 7 to 9, Table 3, suggest that institutions appear to affect growth volatility independently rather than via technical change. Another point of interest is that the estimated effect of technical change increases from -0.54 in the whole world sample, to -0.65 in the sample of ex-colonies, to -0.75 in the sample of upper-income ex-colonies, indicating that for every one percent increase in technical change, growth volatility is reduced by approximately 0.5 to 0.8 percent, which is substantially smaller than the Wald estimate of approximately 2 percent.

Table 4 presents regression results for which institutional quality is measured by expropriation risk. We have a sample of 102 countries for the whole world, a sample of 60 countries for the ex-colonies and a sample of 30 countries for the upper-income ex-colonies. Regression results in Table 4 can be summarized by the following key points: 1) institutional quality by itself is a highly significant explanatory variable of growth volatility, and 2) the significance and strength of institutions in explaining growth volatility diminish after adding technical change and initial income. Taken together, they suggest that the link runs from institutions, to technical change, then to growth volatility.

Overall the simple cross-country OLS results appear to be supportive of our basic hypothesis: technical change is an important channel through which institutional quality exerts its impact on growth volatility. Although the OLS regression results are encouraging, these results could be potentially misleading since institutions and technical change are likely to be endogenous. That is, institutions and technical change affect volatility, but at the same time growth volatility can have a feedback effect on institutions and technical change. We thus need to deal with the endogeneity in institutions and technical change before we can be confident that the resulting estimates reflect causal relationships.

5.2 Instrumental Variables (IV) Regression Results

In this section, we attempt to overcome the simultaneity problem in institutions and technical change using the method of IV estimation. First, a widely-used instrument in empirical research for institutions is the mortality rate of European settlers, which has been shown by Acemoglu, Johnson and Roberson (2001) to be an important determinant of institutional quality and current income level. Second, we use past technical change as an instrument for current technical change. The 2SLS results are reported in Tables 5.[13]

(Table 5 about here)

The first three columns of Table 5 contain regression results for ex-colonies and the last three columns for upper income ex-colonies.[14] Panel A, Table 5, provides second-stage regression results, whereas Panels B and C, Table 5, provide first-stage regression results for the instruments. In Column 1, Panel B, the first-stage regression results show that the mortality rate is a significant determinant of initial constraint, as expected. The statistically significant estimate of -0.533 indicates that the higher the mortality rate of European settlers, the lower is the score of initial constraint on executive power. Column 1, Panel A gives the second-stage regression results of using mortality rate as an instrument for initial constraint to explain growth volatility. As shown in Column 1, Panel A, the exogenous effects of institutions are estimated to be -0.954, which is

[13] To save space, we report and discuss only regression results for which institutions are measured by initial constraint on executive power in this and subsequent sections. As noted earlier, initial constraint on executive power is the preferred measure of institutions.

[14] Recall that the results for the whole world are not presented in this case because of the unavailability of data for the instruments.

statistically significant at the five percent level and its strength is twice as strong as the case when initial constraint is not instrumented by the mortality rate of European settlers (-0.47).

The most important potential problem is a bad instrument: one that is correlated with the omitted variables. An association between the instrumental variable and omitted variables can lead to a bias in the resulting estimates that is much greater than the bias in OLS.[15] As suggested by Murray (2005) and others, we check the error term for any sign of bad instruments. The serial correlation test examines the hypothesis that the error term is not first-order serially correlated. The *P*-value of 0.732 reported in Column 1, Panel A, indicates that there is no evidence of first-order serial correlation. Thus, mortality rate of European settler appears to be an appropriate instrument for initial constraint on executive power.

Column 2, Table 5, reports 2SLS regression results for using both initial constraint and TFP growth to explain growth volatility. In Column 2, Panel A, both initial constraint and TFP growth are instrumented. Their respective first-stage regression results shown in Panel B and C confirm that both mortality rate and past TFP growth are not weak instruments since they are highly correlated with initial constraint and TFP growth, respectively. Column 2, Panel A, shows that the exogenous effects of institutions on growth volatility are substantially reduced when TFP growth is added to the model. TFP growth, on the other hand, is highly significant, implying the exogenous effects of technical change are important determinants of growth volatility. The serial correlation test shows no evidence of first-order serial correlation in the error term, as indicated by the *P*-value of 0.92.

Finally, when we add initial income in Column 3, Table 5, as a control variable, we find that the exogenous effects of institutions have become statistically insignificant, while the exogenous effects of technical change remain highly significant. Mortality rate, however, has become insignificant in the first-stage regression of initial constraint in Column 3, Panel B, owing to the high correlation between initial constraint and initial income.[16]

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[15] See a summary discussion of IV by Angrist and Krueger (2001).
[16] Correlation coefficient between initial constraint and initial income in the different samples is at least 0.5.

Columns 4 to 6, Table 5, repeat the 2SLS regressions using a smaller sample of upper income ex-colonies. The results of the upper income ex-colonies are similar to those of the ex-colonies as a whole in Columns 1 to 3. In Column 5, both institutions and technical change are instrumented and the estimates show the exogenous effects of these variables on growth volatility. It can be seen that the exogenous effects of institutions and technical change are both statistically significant at the one percent level, but those of the institutions have been substantially reduced by the addition of technical change in the model. Similarly, when initial income is added in Column 6, institutions and technical change remain statistically significant. In Column 6, the exogenous effects of institutions are smaller than those in Column 4 where the only explanatory variable is institutions. Also, note that all 2SLS regressions in Column 4 to 6 pass the serial correlation test and their first-stage regressions show no sign of weak instruments.

To sum up the results of 2SLS regressions in Table 5, we reiterate the finding that a substantial part of the estimated exogenous effects of institutions are channeled through technical change since the addition of technical change in the 2SLS regressions reduces both the estimated magnitude and significance of institutions. For example, the estimated effects of institutions on volatility are -0.95 in Column 1, but -0.42 in Column 2, and -1.39 in Column 4, but -0.76 in Column 5. These reductions represent roughly 50 percent drop in the estimated effects of institutions after the exogenous effects of technical change has been accounted for, reflecting the important role of technical change in accounting for the effects of institutions on growth volatility.

5.3 Pooled Cross-Sectional and Panel Fixed-Effects Regressions

In pooled cross-sectional across time regressions, we increase the sample size by pooling random samples drawn from the same population, but at different points in time. As long as the relationship between the dependent and independent variables are constant over time, pooled cross-sectional across-time regressions give more precise estimators and power in test statistics.[17] In Table 6, we show the OLS estimation results of pooled

[17] *t*-statistics used for hypothesis testing have all been corrected for heteroskedasticity and first-order serial correlation in all pooled cross-sectional and panel fixed-effects estimations.

cross-sectional regressions for the whole world (Columns 1 to 4) and for the sample of upper-income countries (Columns 5 to 8).

(Table 6 about here)

Column 1, Table 5, shows that initial constraint on executive power is statistically significant at the one percent level and its estimated effects on growth volatility is -0.192, suggesting that if initial constraint is improved by one score point, the estimated reduction in growth volatility is roughly 0.2 of a percentage point.[18] In Column 2, accounting for TFP growth by itself is estimated to reduce growth volatility by 3.1 percent for every one percent increase in its own value. In Column 3, both initial constraint and accounting TFP growth are statistically significant at the one percent level with relatively little change in their estimated effects in the presence of the other variable. However, in Column 4, when initial income is added to the model, the estimated effects and significance of initial constraint become substantially reduced, while the estimated effects of accounting TFP growth change little and are highly significant.

In Columns 5 to 8, Table 6, we repeat the OLS estimations for the pooled cross-sectional sample of 46 upper-income countries. As noted before, the sample of richer countries is expected to give a better control of the effect of income on growth volatility. The results from this group of upper-income countries are similar to the results in Columns 1 to 4. Specifically, Column 5 indicates that initial constraint by itself is a highly significant explanatory variable of growth volatility and so is accounting TFP growth in Column 6. Column 7 indicates that both initial constraint and accounting TFP growth have independent effects on growth volatility. However, when we added initial income in the model to further control the effects of income, we see that the estimated effects and significance of initial constraint drop substantially while the estimated effects and significance of accounting TFP growth remain relatively unchanged and strong in Column 8.

In sum, Table 6 shows that institutions by itself is an important determinant of growth volatility, but its effects are substantially reduced by adding technical change and

[18] For all pooled cross-sectional and panel fixed regressions, growth volatility is measured by the standard deviation of the trend deviations and technical change measured by the accounting TFP growth.

initial income in the model, reflecting some effects of institutions have been channeling through technical change once we control for the effects of income on growth volatility.

In the panel fixed-effects estimations, we introduce dummy variables to allow for the effects of those omitted variables that are specific to individual countries but stay constant over time, and the effects that are specific to each time period but are the same for all countries. Because institutional quality is relatively constant, its effects on growth volatility cannot be separated from the country fixed-effects. The OLS regression results for the balanced panel data are presented in Table 7.

(Table 7 about here)

Columns 1 and 2, Table 7, contain the results for the balanced panel data of the whole world. Column 1 shows that the effects of technical change on growth volatility by itself becomes considerably weaker and is only marginally significant in the panel fixed-effects estimations. Column 2 shows the effects of technical change on growth volatility increases to -1.775 after controlling for the effects of income and is statistically significant at the five percent level. Both of these estimates indicate that adding 93 country dummy variables to allow for country fixed-effects in the model reduces substantially the estimated effects and statistical significance of technical change on growth volatility.

Columns 3 and 4, Table 7, show results for the balanced panel data of the upper-income countries. The effects of institutional quality alone on growth volatility, as shown in Column 3, is estimated to be roughly -2.54, which is highly significant. Column 4 shows that the estimated effects of technical change increase to -3.53 when initial income is added to the model. Again, the estimated effects of institutional quality are significant at the one percent level after correcting for heteroskedasticity and serial correlation.

On the whole, based upon the results of the panel fixed-effects estimations, we believe that there is strong evidence of a link between technical change and growth volatility even after accounting for all the unobserved country specific factors. All in all, results from pooled cross-sectional and panel fixed-effects estimations are consistent with the cross-country OLS and 2SLS results and are indicative of the important role played by both institutions and technical change, with some of the effects of institutions channeling through technical change.

5.4 Robustness Checking

Previous sections of the paper have implemented various procedures to check for the robustness of the results. These procedures include using different measures of institutions and technical change, different samples and different estimation techniques.

There is a high degree of consistency among our results. In this section, we demonstrate the robustness of our results again by checking alterative model specifications. This question is an important one given the finding of Levine and Renelt (1992) that most results of cross-country growth regressions in the literature are not robust to slight alteration of their model specification. Therefore, it is important to check the sensitivity of our results to alternative model specifications. Specifically, we are concerned with controlling the effects of region, geography, openness to trade, growth, human capital and weather. Tables 8 and 9 present results of robustness checking generated by alternative model specifications to explain growth volatility using pooled cross-sectional estimations. Table 8 uses the whole world sample and Table 9 uses the sample of upper-income countries. Table 10 presents results of robustness checking using panel fixed-effects estimations.

(Table 8 and 9 about here)

First, the question of whether the observed link is driven by results from countries in a particular region is addressed. We add three regional dummies (Africa, Asia and Latin America) to the model in Tables 8 and 9. There is strong evidence to show that Asia has experienced much more stable growth than the other regions, as shown by the highly significant Asia regional variable in all but one regression in Tables 8 and 9. On the other hand, Africa and Latin America do not appear to have any significant impact on growth volatility.

Second, we investigate how geography affects the observed link between institutions, technical change and growth volatility. Geography, which has been found to be an important exogenous variable in the growth literature, is measured by coastal area (proportion of land area within 100 kilometer of the coast) or latitude (distance from the equator). Column 3, Tables 8 and 9, shows that costal area does not appear to be important in explaining growth volatility at all, although there is some evidence of latitude to be growth stabilizing (that is, the further away a country from the equator, the more stable its growth) in Column 4. Third, temperature can also be taken as an attribute of geography, which possibly has an effect on growth volatility. The estimation results for the mean temperature in Column 5, Tables 8 and 9, shows that there is indeed some evidence of destabilizing effects of hotter weather, which is consistent with the estimated effects of latitude on growth volatility.

How do the effects of institutions and technical change on growth volatility change when regional and geography variables are added to the model? As can be seen in Table 8, initial constraint as a measure of institutions bears the wrong sign and is statistically significant. We, however, do not observe such peculiar results in Table 9, where initial constraint is of the right sign and relatively constant across different specifications. The problem with the whole world sample is that the level of income among the 93 countries in the sample displays major differences and their differences in income level may reflect some important underlying country-specific factors that have not been properly accounted for in the pooled-sectional regressions in Table 8. When these omitted country-specific factors are correlated with initial constraint, while at the same time affecting growth volatility, we generate biased estimates of initial constraint as shown in Table 8. However, in Table 9 where the sample consists of only those countries with relatively similar income level, we effectively control for the omitted country-specific factors and generate more accurately the estimated effects of initial constraint on growth volatility. Unlike initial constraint, the results in both Tables 8 and 9 show that the estimated effects of technical change on growth volatility are very stable across different specifications. None of the regional and geography variables reduces the estimated magnitude or significance of technical change.

In Column 6, Tables 8 and 9, we add growth in the model to control for its effects on technical change and volatility. Specifically, we would expect countries that grow faster to also increase their technical change. Hence, it is possible that technical change is only a proxy for past growth. Moreover, output growth and its volatility are really first and second moments of the same variable, so that they are inherently related to each other. To take into account of this possible pitfall, we add growth in the model and check the estimated effects of technical change on growth volatility. Results shown in Column 6, Tables 8 and 9, reconfirm that the estimated effects of technical change are still significant at the one percent level even though there is a sharp drop in its estimated magnitude after adding growth in the model. The results appear to indicate that technical change has some independent effects on growth volatility that cannot be attributed to past or current growth. Another interesting result from Column 6, Tables 8 and 9, is that there appears to be some evidence of a negative correlation between output growth and its volatility, which is consistent with the findings of Ramsey and Ramsey (1995).

The last two columns of Tables 8 and 9 demonstrate, respectively, the impact of human capital and openness to trade on macroeconomic volatility. We measure human capital by the natural logarithm of years of schooling and openness to trade by the sum of exports and imports as a share of GDP. The last two columns of Tables 8 and 9 show that human capital and openness to trade both appear to have little effect on growth volatility since all of their estimates are statistically insignificant at the conventional levels. The estimated effects of technical change, however, remain stable and highly significant with the addition of human capital and openness to trade. Again, these results demonstrate the importance of technical change in reducing growth volatility.

We finish the robustness checking by showing that the estimated effects of technical change on growth volatility hold up against the strict control of panel fixed-effects estimations and the control of growth, human capital or openness to trade in Table 10. Obviously, we cannot include time-invariant effects of regional and geography variables in the model. The estimated effects of technical change on growth volatility from the whole world sample in Column 1 to 4 are only marginally significant after controlling for all unobserved country fixed-effects and the effects of growth, human capital or openness to trade. For the upper-income countries, the results in Column 5 to 8 show unambiguously that technical change reduces growth volatility even after controlling for all unobserved country fixed-effects and the effects of growth, human capital or openness to trade. The panel fixed-effects estimations further boost our confidence of the stabilizing effects of technical change.

(Table 10 about here)

The conclusion of this section on the robustness-checking of our earlier results is as follows. The specification errors in the form of omitted variables do not seem to pose serious problems for our main results. The overwhelming conclusion is that our earlier results are remarkably robust in their general thrust: technical change retains its significance in the face of additional regressors. In 15 of the 20 additional equations estimated, technical change remains significant at one percent, and in a further three cases at five percent. The estimated effects of institutional quality on growth volatility show more variations depending on the regressors and the controls for income level. However, the overall picture appears to be supportive of the earlier claim of institutions as an important determinant of growth volatility.

6. Conclusions

The paper evaluates the technological channel through which institutional quality exerts its influence on growth volatility. It uses three cross-section samples (whole world, ex-colonies and upper income ex-colonies), all of which average data over the period 1970 to 2000. It also constructs two balanced panel data sets, one for the whole world and the other for the upper-income countries, which combine the five 5-year averages of the time-series data over the period 1965 to 1990. The paper uses four econometric methods: cross-country OLS, 2SLS, pooled-sectional and panel fixed-effects estimation techniques. To tackle the potential problem of endogeneity in institutions and technical change, we follow Acemoglu, Johnson and Robinson (2001) in using the mortality rate of European settlers as an instrument for institutions and past technical change for current technical change in 2SLS estimations. Pooled-sectional estimations increase the degrees of freedom and the precision of the estimates, while panel fixed-effects estimations control for all the unobserved country-specific effects. Moreover, the paper tests the robustness of results by experimenting with a large number of alternative specifications suggested in the literature.

In common with the earlier literature, we find that the relations between institutions and growth volatility are statistically significant and economically large. Better institutional quality reduces growth volatility. The key contribution of this paper to the literature is to show that technical change is an important stabilizing force of macroeconomic volatility and that some of the effects of institutions on growth volatility are channeled through technical change. This result is remarkably robust. The effect survives different dependent variables, measures of technical change, measures of institutions and estimation procedures. The effect also survives the addition of a wide variety of further regressors used by others in the literature.

The results of this paper support the view that strong institutional quality is an important factor for accelerating technical change, which provides the economy with the flexibility and ability to reduce macroeconomic volatility. These results, however, do not rule out the possibility that institutional quality has direct effects on macroeconomic volatility, as argued by many, or that there may be other important channels linking institutional quality and macroeconomic volatility. What we have shown is that technical change is an important stabilizing force of macroeconomic volatility and that at least part of the stabilizing force of technical change originates from strong institutions.

References:

Acemoglu, D., Johnson, S., Robinson, J. A., 2001. "Colonial origins of comparative development: an empirical investigation." *American Economic Review*, 91, pp. 1369-1401.

Acemoglu, D., Johnson, S., Robinson, J., Thaicharoen, Y., 2003. "Institutional causes, macroeconomic symptoms: volatility, crises and growth." *Journal of Monetary Economics*, 50, pp. 49-123.

Almeida, H., Ferreira, D., 2002. "Democracy and the variability of economic performance." *Economics and Politics*, 14(3), pp. 225-257.

Angrist, J. D., Krueger, A. B., 2001. "Instrumental variables and the search for identification: From supply and demand to natural experiments." *Journal of Economic Perspectives*, 15(4), pp. 69-85.

Barro, R. J., Lee, J. W., 1993. "International comparisons of educational attainment." *Journal of Monetary Economics*, 32(3), pp. 363-394.

Barro, R. J., Sala-I-Martin, X., 1995. *Economic Growth*. McGraw-Hill: New York.

Blanchard, O., Simon, J., 2001. "The Long and Large Decline in U.S. Output Volatility," *Brookings Papers on Economic Activity*, 1, 135-164.

Braun, M., Larrain, B., 2005. "Finance and Business Cycle: International, Inter-industry Evidence." *Journal of Finance*, 60(3), pp. 1097-1128.

Collins, S. M., Bosworth, B. P., 1996. "Economic Growth in East Asia: Accumulation vs. Assimilation." *Brookings Paper on Economic Activity*, 2, pp. 135-191.

Curtin, P. D., 1968. "Epidemiology and the Slave Trade." *Political Science Quarterly*, 83(2), pp. 181-216.

Da Siva, G. F., 2002. "The Impact of Financial System Development on Business Cycle Volatility: Cross Country Evidence." *Journal of Macroeconomics*, 24(2), pp. 233-253.

Durbin, J., 1954. "Errors in Variables." *Review of the International Statistical Institute*, 22(1/3), pp. 23-32.

Easterly, W., Levine, R., 2001. "It's Not Factor Accumulation: Stylized Facts and Growth Models." *World Bank Economic Review*, 15(2), 177-219.

Easterly, W., Kremer, M., Pritchett, L., Summers, L. H., 1993. "Good policy or good luck? Country growth performance and temporary shocks." *Journal of Monetary Economics*, 32(3), pp. 459-483.

Fogli, A., 2003. "Comment on: 'Institutional causes, macroeconomic symptoms: volatility, crises and growth." *Journal of Monetary Economics*, 50, pp. 125-131.

Gallup, J. L., Sachs, J., Mellinger, A., 1999. "Geography and Economic Development," *International Regional Science Review*, 22(2), pp. 179-232.

Glaeser, E., La Porta, R., Lopez-de-Silanes, F., Shleifer, A., 2004. "Do Institutions Cause Growth," *Journal of Economic Growth*, 9, 271-303.

Hall, R. E., Jones, C. I., 1999. "Why Do Some Countries Produce So Much More Output Per Worker Than Others?" *Quarterly Journal of Economics*, 114(1), pp. 83-116.

Jones, E. L., 1981. *The European miracle: Environments, economics and geopolitics in the history of Europe and Asia*. Cambridge University Press: Cambridge, UK.

Jones, B. F., Olken, B. A., 2005. "Do Leaders Matter? National Leadership and Growth Since World War II." *Quarterly Journal of Economics*, 120(3), pp. 835-864.

King, R., Rebelo, S., 1999. “Resuscitating Real Business Cycles,” in Taylor, John and Woodford, Michael, eds. *Handbook of Macroeconomics*. Volume 1B. New York and Oxford: Elsevier Science, North-Holland, 927-1007.

Knack, S., Keefer, P., 1995. “Institutions and Economic Performance: Cross-Country Test Using Alternative Measures.” *Economics and Politics*, 7, pp. 207-227.

Koren, M., Tenreyro, S., forthcoming. “Volatility and Development.” *Quarterly Journal of Economics*.

La Porta, R., Lopez-de-Silances, F., Shleifer, A., Vishny, R., 1999. “The Quality of Government.” *Journal of Law, Economics, and Organization*, 15(1), pp. 222-279.

Leung, C.K.Y., Tang, S.H.K. and Groenewold, N., 2006. “Growth Volatility and Technical Progress: a Simple Rent-Seeking Model.” *Journal of Economics,* 88(2), pp. 159-178.

Levine, R., Renelt, D., 1992. “A Sensitivity Analysis of Cross-Country Growth Regressions.” *American Economic Review*, 82(4), pp. 942-963.

Martin, P. and Rogers, C. A., 2000. “Long-term Growth and Short-term Economic Stability.” *European Economic Review*, 44, pp. 359-81.

Mauro, P., 1995. “Corruption and Growth.” *Quarterly Journal of Economics*, 110(3), pp. 681-712.

McArthur, J. W., Sachs, J., 2001. "Institutions and Geography: Comment on Acemoglu, Johnson and Robinson.” NBER Working Paper No. 8114, p. 22.

Murray, M., 2006. “Avoiding Invalid Instruments and Coping with Weak Instruments.” *Journal of Economic Perspectives*, 20(4), p.1.

North, D. C., 1981. *Structure and change in economic history*. New York: W. W. Norton & Co.

North, D. C., Thomas, R. P., 1973. *The Rise of the Western World: A New Economic History*. Cambridge University Press: Cambridge, UK.

Parisi, M. L., Schiantarelli, F., Sembenelli, A., 2006. “Productivity, innovation and R&D: Micro evidence for Italy.” *European Economic Review*, 50(8), pp. 2037-2061.

Pedersen, M., 1998. “How Long Are Business-Cycles? Reconsidering Fluctuations and Growth, University of Copenhagen- Institute of Economics Discussion Paper No. 98-24, Copenhagen.

Pritchett, Lant, 2000. “Understanding Patterns of Economic Growth: Searching for Hills among Plateaus, Mountains and Plains.” *World Bank Economic Review*, 14(2), pp. 221-250.

Ramey, G., Ramey, V., 1995. “Cross-Country Evidence on the Links Between Volatility and Growth.” *American Economic Review*, 85, pp. 1138-1151.

Rodrik, D., 1999. “Where Did All the Growth Go?” *Journal of Economic Growth*, 4(4), pp. 385-412.

Sah, R. K., Stiglitz, J. E., 1991. “The quality of managers in centralized versus decentralized organizations.” *Quarterly Journal of Economics,* 106, pp. 289-295

Sachs, J., Warner, A., 1995. “Economic Reform and the Process of Global Integration.” *Brookings Papers on Economic Activity*, 1, pp. 1-118.

Stock, J., Watson, M., 2002. “Has the Business Cycle Changed and Why?” NBER Working Paper No. 9127.

Tang, Sam Hak Kan, 2002. “The Link between Growth Volatility and Technical Progress- Cross-Country Evidence.” *Economics Letters*, 77, pp. 335-341.

Wald, A., 1940. “The fitting of straight lines if both variables are subject to error.” *Annals of Mathematical Statistics*, 11(3), pp. 284-300.

Young, A., 1994. “Lessons from the East Asian NICS: a contrarian view.” *European Economic Review*, 38, pp. 964-973.

Table 1: Means and Standard Deviations of the Key Variables

	Whole world (1)	Ex-colonies (2)	Upper income ex-colonies (3)	Panel data (4)
Standard deviation of annual GDP per capita growth rate (%)	5.58 (3.03)	5.24 (2.20)	4.84 (2.16)	3.90 (3.38)
Average annual GDP per capita growth rate (%)	1.64 (2.06)	1.34 (1.88)	1.78 (1.83)	2.25 (3.24)
Expropriation risk (0 - 10)	6.68 (1.79)	6.59 (1.43)	7.17 (1.46)	6.88 (1.76)
Initial constraint on executive power (1 – 7)	3.52 (2.34)	3.43 (2.10)	4.09 (2.21)	3.93 (2.30)
TFP growth	-0.004 (0.02)	-0.006 (0.01)	-0.005 (0.01)	-0.026 (0.10)
Log real GDP per capita in 1970	7.61 (0.97)	7.44 (0.88)	8.13 (0.61)	7.82 (0.96)
Log European settler mortality	N/A	4.64 (1.29)	3.93 (0.96)	N/A
Number of observations	116	60	30	465

Notes:
1. Mean values of the key variables are reported in the table.
2. Standard deviations are in the parentheses.
3. Detailed descriptions of data series and sources are provided in Section 2, Appendix 1 and 2.
4. Appendix 3 provides key country data for 116 countries over the sample period 1970 – 2000.
5. For the panel data sample in Column (4), growth volatility is measured by the trend deviations and TFP growth calculated by using the growth accounting approach.

Table 2: Estimates of the Return to Technical Change

	Strong initial constraint (1)	Weak to moderate initial constraint (2)	Difference (1) – (2) = (3)
Standard deviation of annual growth rate (%)	3.74	5.56	-1.82 (0.757)
TFP growth (%)	0.29	-0.65	0.94 (0.388)
Number of countries	24	32	
Wald estimate of the return to technical change (%)			-1.93 (1.127)
IV estimate of the return to technical change (%)			-3.05 (1.252)

Notes:
1. Column (1) includes only those countries that show the maximum ranking of 7 for initial constraint on executive power and their initial income above the mean income of the whole world sample in 1970. Column (2) includes all other countries with an initial income above the mean income of the whole world sample in 1970.
2. Figures in the parentheses are standard errors.
3. Detailed descriptions of data series and sources are provided in Appendix 1 and 2.

Table 3: Cross-country OLS Estimations 1970 – 2000 (Institutions Measured by Initial Constraint on Executive Power)

	Whole world			Ex-colonies			Upper income ex-colonies		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Dependent variable is standard deviation of annual GDP per capita growth rate								
Initial const.	-0.47* (-4.90)	-0.38* (-4.05)	-0.35* (-3.23)	-0.38* (-3.42)	-0.39* (-4.03)	-0.43* (-3.97)	-0.48* (-3.12)	-0.52* (-4.03)	-0.51* (-3.39)
TFP growth		-0.54* (-3.67)	-0.54* (-3.68)		-0.65* (-4.24)	-0.65* (-4.27)		-0.75* (-3.60)	-0.75* (-3.52)
Initial income			-0.14 (-0.54)			0.21 (0.82)			-0.03 (-0.05)
Obs.	116	116	116	60	60	60	30	30	30
R-sq.	0.17	0.26	0.26	0.17	0.36	0.38	0.26	0.50	0.50

Notes:
1. Parentheses contain t-ratios.
2. The results are statistically significant at the one (*), five (#) and ten (^) percent levels, against a one-sided alterative.
3. Detailed descriptions of data series and sources are provided in Appendixes 1 and 2.

Table 4: Cross-country OLS Estimations 1970 - 2000 (Institutions Measured by Expropriation Risk)

	Whole world			Ex-colonies			Upper income ex-colonies		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Dependent variable is standard deviation of annual GDP per capita growth rate								
Exp. risk	-0.80* (-6.45)	-0.68* (-5.16)	-0.83* (-4.70)	-0.36# (-2.13)	-0.17 (-1.00)	-0.12 (-0.52)	-0.51# (-2.03)	-0.30 (-1.15)	0.16 (0.37)
TFP growth		-0.41* (-2.60)	-0.34# (-2.08)		-0.56* (-3.04)	-0.58* (-2.99)		-0.54# (-1.93)	-0.74# (-2.33)
Initial income			0.40^ (1.31)			-0.12 (-0.34)			-1.24 (-1.29)
Obs.	102	102	102	60	60	60	30	30	30
R-sq.	0.29	0.34	0.35	0.07	0.20	0.20	0.10	0.18	0.20

Notes:
1. Parentheses contain *t*-ratios.
2. The results are statistically significant at the one (*), five (#) and ten (^) percent levels, against a one-sided alterative.
3. Detailed descriptions of data series and sources are provided in Appendix 1 and 2.

Table 5: Cross-country 2SLS Estimations 1970 – 2000

	Ex-colonies (No. of countries = 60)			Upper income ex-colonies (No. of countries = 30)		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Dependent variable is standard deviation of annual GDP per capita growth rate						
Initial constraint	-0.954# (-2.347)	-0.420^ (-1.509)	-0.915 (-0.965)	-1.394* (-2.621)	-0.764* (-3.045)	-1.028# (-2.079)
TFP growth		-0.571* (-2.983)	-0.641* (-3.038)		-0.923* (-3.413)	-0.952* (-3.059)
Initial income			0.723 (0.701)			0.917 (0.862)
Serial correl. test (*p*-values)	0.732	0.920	0.765	0.341	0.632	0.719
R-square	0.168	0.364	0.324	0.258	0.494	0.460
Panel B: First-stage regressions for initial constraint on executive power						
Mortality rate	-0.533* (-2.650)	-0.605* (-2.876)	-0.226 (-0.873)	-0.998* (-2.553)	-1.235* (-3.190)	-0.861# (-1.879)
Lag TFP growth		-0.172 (-1.138)	-0.113 (-0.768)		-0.509# (-2.068)	-0.380^ (-1.478)
Initial income			0.858# (2.349)			1.017^ (1.459)
R-square	0.108	0.128	0.206	0.189	0.300	0.353
Panel C: First-stage regressions for TFP growth						
Mortality rate		-0.003* (-3.443)	-0.005* (-4.905)		-0.004# (-2.419)	-0.004# (-2.068)
Lag TFP growth		0.513* (8.660)	0.483* (8.663)		0.630* (6.191)	0.623* (5.644)
Initial income			-0.004* (-3.211)			-0.001 (-0.180)
R-square		0.669	0.721		0.683	0.683

Notes:

1. Parentheses contain *t*-statistics.
2. The results are statistically significant at the one (*), five (#) and ten (^) percent levels, against a one-sided alterative.
3. The serial correlation test has a null hypothesis that the errors exhibit no first-order serial correlation.
4. Detailed descriptions of data series and sources are provided in Appendix 1 and 2.

Table 6: Pooled Cross-Sectional OLS Estimations 1965 – 1990

	Whole world No. of countries = 93				Upper income countries No. of countries = 46			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable is the standard deviation of errors from an autoregressive equation for annual GDP per capita growth rate								
Initial constraint	-0.192* (-2.92)		-0.185* (-2.83)	0.069^ (1.33)	-0.291* (-3.36)		-0.285* (-3.33)	-0.150^ (-1.55)
Accounting TFP growth		-3.062* (-2.49)	-2.982* (-2.63)	-2.311* (-3.02)		-3.14* (-3.94)	-2.730* (-2.96)	-2.697* (-3.22)
Initial income				-1.109* (-5.65)				-1.035* (-4.40)
1970 – 74	1.730* (9.31)	1.738* (8.49)	1.741* (9.55)	1.946* (10.00)	1.074* (11.81)	1.045* (7.55)	1.082* (10.06)	1.262* (9.81)
1975 – 79	0.950* (4.45)	0.940* (4.01)	0.938* (4.52)	1.210* (5.58)	1.156* (9.45)	1.130* (6.01)	1.134* (7.82)	1.502* (9.36)
1980 – 84	1.461* (6.67)	1.463* (6.13)	1.430* (6.76)	1.904* (8.73)	1.466* (11.04)	1.450* (7.00)	1.463* (9.28)	1.850* (10.98)
1985 – 89	0.994* (4.75)	0.806* (3.13)	0.798* (3.50)	1.276* (5.85)	1.416* (10.84)	1.314* (6.45)	1.331* (8.59)	1.753* (10.31)
Obs.	465	465	465	465	230	230	230	230
R-squared	0.08	0.07	0.09	0.17	0.15	0.09	0.16	0.22

Notes:
1. Numbers in parentheses are heteroskedasticity and time-correlated robust *t*-statistics.
2. The results are statistically significant at the one (*), five (#) and ten (^) percent levels, against a one-sided alterative.
3. Detailed descriptions of data series and sources are provided in Appendix 1 and 2.

Table 7: Panel Fixed-Effects OLS Estimations 1965 – 1990

	Whole world No. of countries = 93		Upper income countries No. of countries = 46	
	(1)	(2)	(3)	(4)
Dependent variable is the standard deviation of errors from an autoregressive equation for annual GDP per capita growth rate				
Accounting TFP growth	-1.527^ (-1.31)	-1.775# (-1.69)	-2.538* (-3.55)	-3.534* (-5.86)
Initial income		-1.262 (-1.23)		-3.055* (-2.77)
1970 – 74	1.917* (1384.00)	2.144* (11.68)	1.178* (561.40)	1.796* (8.06)
1975 – 79	0.890* (576.00)	1.275* (4.07)	1.204* (214.70)	2.265* (5.90)
1980 – 84	1.548* (125.90)	2.084* (4.74)	1.283* (128.70)	2.671* (5.32)
1985 – 89	1.021* (13.48)	1.549* (3.37)	1.359* (57.12)	2.766* (5.40)
Obs.	465	465	230	230
R-squared	0.35	0.36	0.42	0.45

Notes:

1. All regressions include unreported country fixed effects.
2. Numbers in parentheses are heteroskedasticity and time-correlated robust *t*-statistics.
3. The results are statistically significant at the one (*), five (#) and ten (^) percent levels, against a one-sided alterative.
4. Detailed descriptions of data series and sources are provided in Appendix 1 and 2.

Table 8: Robustness Checks (The Whole World, Pooled Cross-Sectional OLS Estimations 1965 – 1990)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable is the standard deviation of errors from an autoregressive equation for annual GDP per capita growth rate								
Initial constraint	0.069^ (1.33)	0.070^ (1.31)	0.133* (2.64)	0.119* (2.37)	0.119* (2.34)	0.067 (1.22)	0.150* (3.11)	0.105# (2.19)
Accounting TFP growth	-2.311* (-3.02)	-2.107* (-2.65)	-2.421* (-2.36)	-2.478* (-2.33)	-2.404# (-2.29)	-1.897* (-2.55)	-2.225# (-1.90)	-2.536# (-1.76)
Initial income	-1.109* (-5.65)	-1.065* (-4.40)	-1.251* (-5.07)	-1.184* (-5.09)	-1.182* (-5.65)	-1.061* (-4.36)	-1.165* (-5.40)	-1.489* (-5.34)
Asia		-0.699* (-3.16)	-0.696* (-2.77)	-1.141* (-4.77)	-1.005* (-2.99)	-0.618# (-2.27)	-0.809* (-4.29)	-1.198* (-3.83)
Africa		0.221 (0.36)	-0.294 (-0.65)	-0.509 (-1.16)	-0.2779 (-0.51)	0.100 (0.16)	-0.388 (-0.69)	-0.943 (-1.24)
Latin America		0.154 (0.23)	0.172 (0.25)	-0.270 (-0.44)	-0.073 (-0.09)	0.042 (0.06)	0.126 (0.19)	-0.322 (-0.46)
Coastal area			-0.411 (-1.10)					
Latitude				-1.559# (-2.29)				
Mean temp.					0.025 (0.88)			
Growth						-0.049 (-0.93)		
Human capital							-0.326 (-0.92)	
Openness to trade								0.003 (0.51)
1970 – 74	1.946* (10.00)	1.867* (10.01)	1.896* (9.76)	1.862* (10.06)	1.857* (10.29)	1.832* (9.99)	1.900* (9.63)	2.087* (10.34)
1975 – 79	1.210* (5.58)	1.171* (5.56)	1.275* (5.81)	1.219* (5.92)	1.213* (6.02)	1.139* (5.07)	1.373* (6.18)	1.421* (6.33)
1980 – 84	1.904* (8.73)	1.834* (8.43)	1.897* (8.55)	1.872* (8.96)	1.863* (9.10)	1.680* (6.13)	2.038* (8.71)	2.195* (9.84)
1985 – 89	1.276* (5.85)	1.232* (5.58)	1.351* (6.26)	1.304* (6.20)	1.293* (6.08)	1.148* (4.65)	1.487* (5.76)	1.557* (7.05)
Obs.	465	465	455	455	455	465	450	430
R-squared	0.17	0.17	0.18	0.19	0.18	0.17	0.18	0.19

Notes:

1. Numbers in parentheses are heteroskedasticity and time-correlated robust *t*-statistics.
2. The results are statistically significant at the one (*), five (#) and ten (^) percent levels, against a one-sided alterative.
3. Detailed descriptions of data series and sources are provided in Appendix 1 and 2.

Table 9: Robustness Checks (Upper-Income Countries, Pooled Cross-Sectional OLS Estimations 1965 – 1990)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable is the standard deviation of errors from an autoregressive equation for annual GDP per capita growth rate								
Initial constraint	-0.150^ (-1.55)	-0.206# (-1.81)	-0.220# (-1.82)	-0.209# (-1.79)	-0.194^ (-1.47)	-0.172# (-1.65)	-0.195# (-1.76)	-0.266# (-1.92)
Accounting TFP growth	-2.697* (-3.22)	-2.726* (-3.08)	-2.718* (-3.03)	-2.872* (-3.34)	-3.071* (-3.44)	-1.894* (-2.33)	-2.689* (-3.02)	-3.661* (-2.87)
Initial income	-1.035* (-4.40)	-1.138* (-2.62)	-1.095* (-2.69)	-1.039* (-2.43)	-0.772# (-2.02)	-1.366* (-2.96)	-1.101* (-2.47)	-1.241* (-3.18)
Asia		-0.593* (-2.96)	-0.705* (-2.38)	-0.890* (-3.18)	-0.927* (-3.65)	-0.003 (-0.01)	-0.581* (-2.64)	-0.703* (-2.23)
Africa		-0.080 (-0.12)	0.007 (0.01)	-0.163 (-0.23)	-0.012 (-0.02)	-0.468 (-0.76)	-0.085 (-0.13)	-0.286 (-0.53)
Latin America		-0.509 (-0.97)	-0.532 (-0.95)	-0.795 (-1.13)	-0.756^ (-1.28)	-0.924# (-1.79)	-0.509 (-0.95)	-0.893# (-1.91)
Coastal area			0.175 (0.45)					
Latitude				-1.084 (-1.02)				
Mean temp.					0.049# (1.80)			
Growth						-0.150* (-2.40)		
Human capital							-0.068 (-0.16)	
Openness to trade								-0.002 (-0.39)
1970 – 74	1.262* (9.81)	1.294* (7.50)	1.288* (7.54)	1.286* (8.03)	1.160* (7.52)	1.257* (7.95)	1.294* (7.77)	1.444* (8.14)
1975 – 79	1.502* (9.36)	1.550* (7.05)	1.536* (7.21)	1.488* (7.18)	1.340* (6.53)	1.368* (5.89)	1.552* (7.19)	1.716* (8.15)
1980 – 84	1.850* (10.98)	1.910* (7.86)	1.893* (8.16)	1.880* (8.19)	1.815* (8.08)	1.401* (4.40)	1.907* (7.65)	2.229* (10.32)
1985 – 89	1.753* (10.31)	1.800* (7.93)	1.776* (8.10)	1.741* (7.83)	1.592* (7.02)	1.547* (5.92)	1.813* (7.56)	2.074* (9.35)
Obs.	230	230	230	230	225	230	230	210
R-squared	0.22	0.23	0.23	0.23	0.24	0.25	0.22	0.24

Notes:
1. Numbers in parentheses are heteroskedasticity and time-correlated robust *t*-statistics.
2. The results are statistically significant at the one (*), five (#) and ten (^) percent levels, against a one-sided alterative.
3. Detailed descriptions of data series and sources are provided in Appendix 1 and 2.

Table 10: Robustness Checks (Panel Fixed-Effects OLS Estimations 1965 – 1990)

	Whole world No. of countries = 93				Upper income countries No. of countries = 46			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable is the standard deviation of errors from an autoregressive equation for annual GDP per capita growth rate								
Accounting TFP growth	-1.775# (-1.69)	-1.412^ (-1.30)	-2.721* (-2.05)	-2.592^ (-1.57)	-3.534* (-5.86)	-2.680* (-5.01)	-3.974* (-6.29)	-5.045* (-4.23)
Initial income	-1.262 (-1.23)	-1.502^ (-1.63)	-1.505^ (-1.47)	-1.298^ (-1.26)	-3.055* (-2.77)	-3.453* (-3.35)	-2.867* (-2.45)	-2.653* (-2.29)
Growth		-0.121# (-1.92)				-0.182* (-3.30)		
Human capital			-0.504 (-0.55)				1.860^ (1.60)	
Openness to trade				0.001 (0.13)				0.000 (0.03)
1970 – 74	2.144* (11.68)	2.221* (13.40)	2.267* (10.92)	2.289* (13.16)	1.796* (8.06)	1.811* (8.66)	1.543* (4.51)	1.790* (8.28)
1975 – 79	1.275* (4.07)	1.265* (4.44)	1.581* (4.23)	1.417* (4.67)	2.265* (5.90)	2.085* (5.65)	1.848* (3.20)	2.229* (5.88)
1980 – 84	2.084* (4.74)	1.902* (4.49)	2.442* (4.36)	2.228* (5.24)	2.671* (5.32)	2.229* (4.45)	2.015* (2.48)	2.691* (5.51)
1985 – 89	1.549* (3.37)	1.456* (3.42)	1.962* (2.95)	1.690* (3.78)	2.766* (5.40)	2.495* (5.06)	2.000# (2.28)	2.757* (5.54)
Obs.	465	465	450	430	230	230	230	210
R-squared	0.36	0.37	0.36	0.36	0.45	0.47	0.46	0.46

Notes:
1. All regressions include unreported country fixed effects.
2. Numbers in parentheses are heteroskedasticity and time-correlated robust *t*-statistics.
3. The results are statistically significant at the one (*), five (#) and ten (^) percent levels, against a one-sided alterative.
4. Detailed descriptions of data series and sources are provided in Appendix 1 and 2.

Figure 1: Institutions and Technical Change

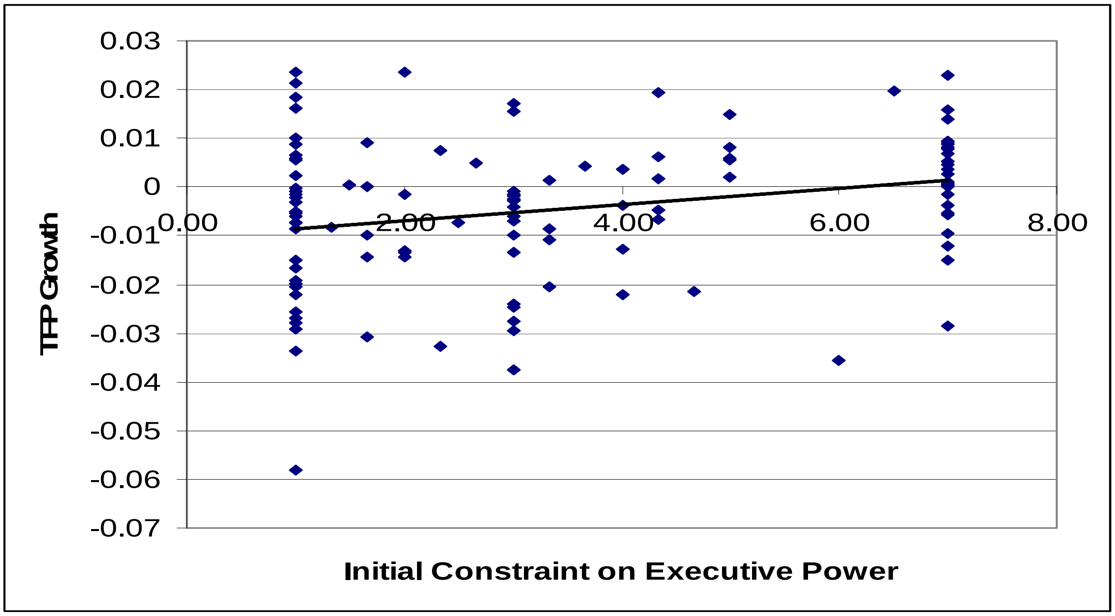
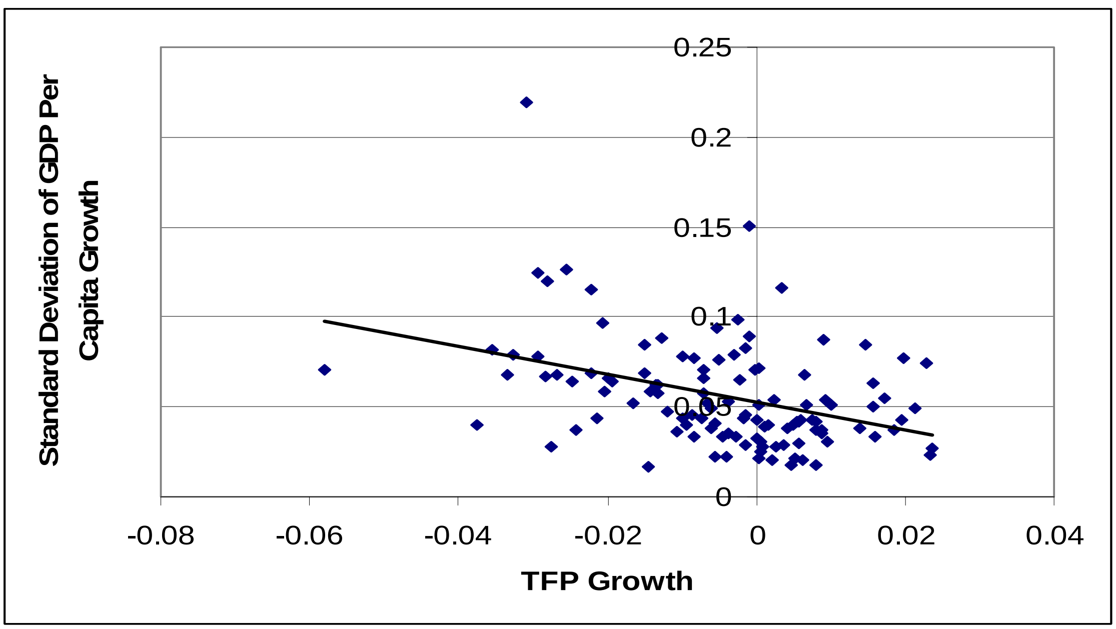


Figure 2: Technical Change and Macroeconomic Volatility



Appendix 1: Data and Sources

1. Africa: Dummy variable taking the value of 1 if a country belongs to Africa, 0 otherwise.
2. Asia: Dummy variable taking the value of 1 if a country belongs to Asia, 0 otherwise.
3. Coastal area: Proportion of land area within 100 km of the seacoast. From Gallup, Sachs and Mellinger (1999).
4. Expropriation risk: The risk of "outright confiscation" or "forced nationalization" assessed by *International Country Risk Guide*. It is scaled from zero to ten, with lower scores for higher risks. We average the months of January of the monthly index between 1984 and 1995.
5. Growth: Average annual GDP per capita growth rate for the period 1970 – 2000. Annual GDP per capita growth rate is calculated by subtracting the annual population growth rate from the annual GDP growth rate for every year between 1970 and 1998. Data are taken from *2002 World Development Indicators CD-ROM*.
6. Human capital: Natural logarithm of one plus the average years of schooling for the period 1970-90. Data are available from Barro and Lee (1993).
7. 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. We average the scores for 1950, 1960 and 1970 to obtain the average initial constraint. Data are available from *Polity III* dataset compiled by Keith Jaggers and Ted Robert Gurr, 1996, Inter-University Consortium for Political and Social Research.
8. Latin America: Dummy variable taking the value of 1 if a country belongs to Latin America or the Caribbean, 0 otherwise.
9. Latitude: Absolute value of the latitude of the country, which is a measure of distance from the equator, scaled to take values between 0 and 1, where 0 is the equator. See La Porta et al. (1999).
10. Log European settler mortality: The mortality rates of soldiers, bishops and sailors stationed in the colonies between the seventeenth and nineteenth centuries. Data are obtained from Acemoglu, Johnson and Robinson (2001), which in turn constructed the data from the original work of Philip D. Curtin (1968).
11. Log initial GDP per capita: Natural logarithm of real GDP per capita at the beginning of the sample period, 1970. Data are from *Penn World Table 6.1* (RGDPL, Laspeyres index).
12. Macroeconomic or growth volatility: For cross-country data regressions, volatility is measured by the standard deviation of annual real GDP per capita growth rate for the period 1970 - 2000. See "Growth" in this section. For panel data regressions, 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, $GD\dot{P}_t = a_0 + a_1 GD\dot{P}_{t-1} + a_2 GD\dot{P}_{t-2} + a_3 GD\dot{P}_{t-3} + \varepsilon$. 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.

13. Mean temperature: 1987 mean annual temperature in degrees Celsius from McArthur and Sachs (2001).
14. Openness to trade: The average ratio of nominal imports plus exports to GDP in Purchasing-Power-Parity US dollars (PPP GDP) for the period 1970-90. Data are available from *Penn World Table Mark 5.6*.
15. TFP growth: A measure of technical change. We use two alternative methods to calculate TFP growth. The first one uses a cross-country regression technique and the second one uses growth accounting framework. See Appendix 2 for a detailed discussion.

Appendix 2: More details on the data construction

This appendix provides more details on our measures of technical change. Technical change is commonly estimated by TFP growth in the literature. One approach to obtaining TFP growth is to regress the growth of output per worker on a constant and the growth of physical capital stock per worker across countries as follows:[19]

$$\text{(A1)} \quad \Delta\left(\frac{y}{l}\right)_i = \beta_0 + \beta_1 \Delta\left(\frac{k}{l}\right)_i + E_i$$

where $\Delta(y/l)_i$ and $\Delta(k/l)_i$ denote, respectively, the growth of output per worker and capital stock per worker for country i for the period 1970-2000. The constant, β_0, represents the world average TFP growth, while the residual for each country, E_i, represents the country's TFP growth over and above the world average. Physical capital stock in equation (A1) is calculated by the perpetual inventory method with a common geometric depreciation rate of 0.04 and with cumulating investment flows for up to 20 years (1950-69), which provides a benchmark of capital stock for each country in 1970. We then extend the series of capital stock to 2000 using investment data for 1970-2000. *Penn World Table 6.1* provides the source of data on per worker GDP, investment and the labor force. Regressing equation (A1) across 120 countries yields the following result:

$$\text{(A2)} \quad \Delta\left(\frac{y}{l}\right)_i = -0.09 + \underset{(8.7439)}{0.41}\Delta\left(\frac{k}{l}\right)_i + E_i \qquad R^2 = 0.63$$

The cross-country regression result in equation (A2) shows that the estimated capital share of income is 0.41 with a t-ratio of 8.7439.[20] The world average growth of TFP for the period 1970-2000 is estimated to be –0.09 percent. Adding the estimated residual for each country to the world average growth of TFP of –0.09 gives the growth rate of TFP for that country for the regression period.

[19] See Alwyn Young (1994) for a discussion of this approach.

[20] Our estimate of β_1, the capital share of income, is roughly the same as that estimated by Young (1994), who finds β_1 to be 0.45.

An alternative measure of technical change, which serves as a robustness check in panel data regressions, is derived from a non-parametric growth accounting framework that resembles Collins and Bosworth (1996). TFP growth for each country is calculated by:

$$\text{(A3)} \quad \Delta\left(\frac{y}{l}\right)_t = \alpha\Delta\left(\frac{k}{l}\right)_t + (1-\alpha)\Delta h_t + a$$

where $\Delta(y/l)_t$, $\Delta(k/l)_t$ and Δh_t represent the growth of output per worker, physical capital per worker and education per worker, respectively, at each time period, t. The last term in Equation (A3), a, represents the growth rate of TFP. The weight in Equation (A3), 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 93 sample countries. Since data on education per worker for some countries are unavailable from Barro and Lee (1993), we have a smaller sample of TFP growth than the one generated by the cross-country regression.

Appendix 3: Key Country Data

1970 – 2000	Initial constraint (1 – 7)	Expro. Risk (1 - 10)	TFP growth %	Acct TFP growth %	Std. dev. growth %	Log GDP/ capita 70	GDP growth %
Algeria	1.00	6.50	-0.84	-4.35	6.20	7.51	-14.37
Angola	1.00	5.36	-2.80	N/A	7.87	7.07	-27.17
Argentina	1.67	6.39	-1.42	-2.13	5.60	8.64	-9.09
Australia	7.00	9.32	0.02	0.14	1.96	9.28	-4.07
Austria	7.00	9.22	0.36	-0.16	1.91	8.92	-0.46
Bangladash	1.00	5.14	0.59	-2.39	4.84	7.16	-16.73
Barbados	1.00	N/A	-0.72	N/A	4.30	8.44	-5.75
Belgium	7.00	8.86	0.51	0.56	2.07	9.03	-1.89
Benin	3.00	N/A	-2.41	N/A	3.59	7.01	-7.51
Bolivia	1.67	5.64	0.02	-0.13	3.07	7.41	-6.35
Bostwana	7.00	6.44	1.58	0.07	5.87	6.70	-0.72
Brazil	3.67	7.91	0.42	0.03	4.58	7.79	-6.62
Burkina Faso	2.50	4.45	-0.74	N/A	3.59	5.92	-4.27
Burundi	1.00	N/A	-0.53	N/A	6.43	5.83	-10.47
Cameroon	3.00	6.45	-1.34	-2.69	7.08	6.69	-10.63
Canada	7.00	9.73	0.27	-0.13	2.26	9.22	-4.25
Cape Verde Is	1.00	N/A	-0.30	N/A	2.98	6.46	-1.31
Central Afr. Rep	1.00	N/A	-0.72	N/A	4.42	6.61	-10.52
Chad	1.00	N/A	-2.55	N/A	8.75	6.49	-23.68
Chile	4.00	7.82	-0.37	-0.66	5.83	8.19	-12.95
China	2.00	6.34	-0.14	-1.01	4.11	6.54	-3.11
Colombia	4.33	7.32	0.62	-0.62	1.90	7.67	-1.41
Comoros	1.00	N/A	-2.00	N/A	3.98	6.55	-8.02
Congo	3.00	4.68	-0.09	-4.13	7.23	7.42	-11.81
Costa Rica	7.00	7.05	-0.95	-2.01	3.70	7.97	-10.27
Cyprus	6.50	7.80	1.98	0.53	4.90	8.23	-1.15
Czechoslovakia	3.00	7.28	-0.18	-0.35	5.26	7.83	-11.09
Denmark	7.00	8.61	0.06	-0.16	2.03	9.18	-2.03
Domincan Rep	1.67	6.18	-1.00	-1.55	4.37	7.34	-7.94
Ecuador	2.33	6.55	0.75	-0.92	5.25	7.49	-8.46
Egypt	4.33	6.77	0.16	-3.81	3.16	7.06	-1.14
El Savador	3.33	5.00	-1.07	-2.13	4.52	7.50	-13.30
Ethiopia	1.00	5.73	0.24	N/A	8.55	5.69	-21.15
Finland	7.00	8.70	0.89	0.62	3.22	9.00	-6.82
France	5.00	8.85	0.21	-0.60	1.48	9.13	-1.28
Gabon	1.00	7.82	-2.06	N/A	12.54	8.21	-26.98
Gambia	7.00	8.27	-2.84	-4.53	3.40	6.59	-4.36
Germany	7.00	9.80	0.47	0.38	1.34	9.15	-1.75
Ghana	3.00	6.27	-1.00	-2.12	4.97	6.97	-14.63
Greece	5.00	6.03	0.58	-0.36	2.89	8.35	-4.01
Guatemala	3.00	5.14	-0.40	-1.92	2.77	7.61	-6.05
Guinea	1.00	6.55	1.86	N/A	1.06	6.15	-0.49
Guinea-Biss	1.00	3.71	-0.09	N/A	8.64	6.56	-30.21
Guyana	6.00	5.89	-3.54	-4.48	5.36	7.50	-14.23
Honduras	3.00	5.32	-0.16	-2.46	3.27	7.12	-4.61
Hong Kong	1.00	8.14	2.12	0.99	4.82	8.41	-7.32
Hungary	3.00	6.54	-3.76	-3.05	4.02	8.12	-11.71
India	7.00	8.27	0.95	-0.78	3.25	6.69	-7.52

Indonesia	3.33	7.59	0.12	-0.88	4.12	6.57	-14.63
Iran	2.33	4.37	-3.28	-6.78	8.10	8.49	-16.27
Iraq	1.67	2.02	-3.09	-8.29	21.98	8.39	-53.68
Israel	7.00	6.23	0.67	0.32	2.81	8.70	-2.25
Ivory Coast	1.00	7.00	-1.66	N/A	4.98	7.39	-14.75
Jamaica	7.00	7.09	-1.20	-2.54	5.06	7.88	-7.68
Japan	7.00	9.72	0.80	0.22	2.70	8.90	-3.13
Jordan	1.67	5.16	0.90	-1.30	8.35	7.26	-17.05
Kenya	3.00	6.05	1.71	-0.37	4.99	6.38	-8.05
Korea, Rep	4.33	8.69	1.95	0.47	4.05	7.42	-7.64
Lesotho	1.00	N/A	-0.21	N/A	7.89	6.04	-15.85
Luxembourg	7.00	9.66	1.38	N/A	3.34	9.19	-7.44
Madagascar	3.00	4.45	-2.74	N/A	3.59	7.04	-12.28
Malawi	1.00	5.31	-0.01	-1.23	5.73	6.09	-12.98
Malaysia	5.00	7.95	0.57	-0.89	4.09	7.68	-9.71
Mali	2.00	4.00	-1.33	-4.53	5.28	6.04	-7.64
Malta	1.00	7.23	2.34	2.07	3.95	7.80	0.69
Mauritania	3.00	N/A	-2.94	N/A	4.21	6.77	-7.51
Mauritius	7.00	N/A	2.29	N/A	5.27	7.78	-11.58
Mexico	3.00	7.50	-0.27	-1.87	3.77	8.29	-7.94
Morocco	1.50	7.09	0.03	N/A	4.78	7.21	-8.34
Mozambique	1.00	4.89	-0.14	-5.25	8.19	7.31	-18.11
Myanmar	5.00	2.27	0.81	-1.54	4.21	6.04	-12.92
Namibia	1.00	5.05	-0.51	N/A	2.84	7.87	-4.46
Nepal	1.33	N/A	-0.83	N/A	3.01	6.52	-5.57
Netherlands	7.00	9.37	0.10	-0.15	1.58	9.13	-1.63
New Zealand	7.00	9.73	-0.56	-0.98	2.58	9.15	-5.16
Nicaragua	1.00	5.23	-3.35	-4.06	7.13	7.77	-29.59
Niger	3.00	5.00	-2.47	-6.44	6.91	6.69	-20.18
Nigeria	4.00	5.55	-1.27	N/A	7.24	6.64	-16.26
Norway	7.00	9.30	0.80	0.38	1.74	8.99	-0.64
Pakistan	2.67	6.05	0.50	-0.33	2.64	6.94	-2.67
Panama	3.33	5.91	-0.85	-2.26	4.66	7.86	-15.41
Papua N. Guinea	1.00	6.28	-1.94	-5.10	5.53	7.55	-6.16
Paraguay	1.00	6.95	-0.60	-0.95	4.14	7.24	-6.62
Peru	3.33	5.77	-2.04	-3.03	5.93	7.91	-14.16
Philippines	4.33	4.71	-0.46	-1.27	3.72	7.25	-9.58
Portugal	1.00	8.01	1.60	0.63	4.03	8.11	-8.15
Puerto Rico	1.00	N/A	1.00	N/A	3.04	8.66	-4.39
Rwanda	1.00	N/A	-2.21	N/A	10.12	6.47	-31.12
Saudi Arabia	1.00	6.33	-5.81	N/A	7.02	8.97	-16.82
Senegal	3.00	6.00	-0.59	-1.82	4.72	7.05	-8.50
Seychelles	1.00	5.82	0.64	N/A	6.81	7.42	-9.34
Sierria Leone	4.00	9.32	-2.22	-4.99	5.82	7.27	-20.12
Singapore	5.00	6.86	1.48	0.85	3.22	8.01	-1.51
South Africa	7.00	8.15	-0.55	-0.66	3.86	8.09	-6.59
Spain	1.00	6.05	0.55	-0.03	2.21	8.68	-1.36
Sri Lanka	7.00	4.00	-0.15	-0.63	1.77	7.12	-2.40
Suriname	1.00	6.33	-2.68	N/A	6.80	8.02	-16.43
Swaziland	2.00	N/A	-1.45	N/A	4.58	7.83	-5.28
Sweden	7.00	9.04	0.03	-0.57	1.94	9.28	-2.80
Switzerland	7.00	9.95	-0.38	-1.10	2.36	9.47	-6.69
Syria	4.00	4.26	0.35	-2.29	8.26	7.74	-12.26

Taiwan	2.00	9.15	2.36	1.21	3.03	7.69	1.06
Tanzania	3.00	6.64	-0.24	N/A	1.96	6.05	-2.51
Thailand	3.00	7.25	1.56	0.70	4.37	7.33	-10.88
Togo	1.00	6.91	-1.49	-6.24	6.50	6.42	-18.25
Trinidad&Tobago	7.00	7.45	-1.50	-2.30	5.08	8.82	-7.10
Tunisia	1.00	6.45	0.89	-2.60	3.94	7.27	-4.60
Turkey	7.00	5.45	0.92	-0.42	3.65	7.70	-7.27
U.K.	7.00	9.55	0.52	0.31	2.17	9.05	-2.34
U.S.A.	7.00	10.00	0.05	-0.45	2.23	9.47	-2.97
Uganda	3.00	4.45	-0.70	-1.65	3.44	6.47	-5.29
Uruguay	4.33	7.00	-0.67	-1.26	4.51	8.33	-10.92
Venezuela	4.67	7.14	-2.15	-3.73	4.22	8.95	-11.30
Zaire	1.00	3.50	-2.92	-5.96	5.10	6.53	-16.67
Zambia	2.00	4.09	-1.32	-3.44	4.22	7.01	-11.48
Zimbabwe	7.00	5.03	0.03	-0.68	6.20	6.99	-10.97