THE UNIVERSITY OF WESTERN AUSTRALIA
Business School

ECONOMICS

Scientific Research and Growth Volatility

By

Sam Tang
The University of Western Australia

DISCUSSION PAPER 08.11

Scientific Research and Growth Volatility

Sam Hak Kan Tang*

Abstract:
This article uncovers a strong link between scientific and engineering publications on the one hand, and growth volatility on the other: growth volatility is significantly lowered by a country's ability to publish more scientific and engineering journal articles. This link is strongest among the high-income developed countries, where we find causality running from scientific research output to growth volatility. The evidence suggests that scientific research fuels technological progress and productivity growth, which support population increase, diversification, and stable economic growth. The key finding of this article is robust to various sensitivity checks and different estimators.

Keywords: Scientific research, Publications, Growth volatility, Population, Diversification

JEL classifications: O11, O33, E32

* Business School, The University of Western Australia, 35 Stirling Highway, Crawley WA 6009, Australia
Email: sam.tang@uwa.edu.au; tel.: +618-6488-2931; fax: +618-6488-1016.

1. Introduction

Developing countries regularly experience large swings of economic activities. The traditional notion that some countries never experience any growth does not accurately describe the real world. Even the poorest countries experience periods with growth spurts, which, for a short time, raise hopes that the countries will catch up with the rest of the world. However, then their miraculous growth spurts decline and hopes of reducing poverty in the world are dashed. These volatile patterns of growth in developing countries have been well documented by Easterly et al. (1993), Pritchett (2000) and Jones and Olken (2005).

The human costs of volatile growth are enormous. In addition to the vast increase in the number of unemployed poor, severe recessions hit those who are most vulnerable especially hard. Paxson and Schady (2004) analyze the impact of the profound 1988-92 recession in Peru on infant mortality and show that there was an increase of about 2.5 percentage points in the infant mortality rate for children born in late 1989 and 1990, implying that about 17,000 more children died than would have in the absence of the recession. Cruces and Wodon (2003) find that households without the means to diversify their income sources suffered more than others from the Argentina's economic collapse of 2002.

(Figure 1 about here)

Figure 1 shows the extent of growth variations for countries of different income levels. It shows that low-income developing countries in 1960 experienced more diversified growth rates for the past 40 years than those of the high-income developed countries, whose growth rates are highly stable at around 2 percent over time. Both Botswana (BWA) and Congo Democratic Republic (ZAR), for example, shared similar income levels in 1960, but Botswana achieved an impressive annual growth rate of 6.9 percent for the past 40 years compared to -2.5 percent for Congo Democratic Republic. In Table 1, we show the differences in the variance of growth rates between high-income developed countries and the rest of the world over time. Table 1 highlights an important observation about growth volatility in the past 40 years: the rest of the world consistently experienced growth volatility that is roughly three to four times higher than that of high-income developed countries. What causes a country’s growth to be so much more volatile?

(Table 1 around here)

This paper examines a basic determinant of growth volatility: scientific research as a natural component of technological progress. We believe that much of the observed difference in growth volatility between high-income developed and low-income developing countries can be attributed to country differences in the ability to innovate and engage in sustained technological progress. High-income countries, with stronger institutional quality and greater financial resources, are able to invest heavily in research and development (R&D), which not only expands their scientific knowledge frontier, but also transforms scientific knowledge into technology and practical applications, which develop new and better products or processes. The outcomes of such research combined to increase the technological capability of the high-income countries.

The mechanisms through which technological progress affects growth volatility need to be considered. First, technological progress is an important factor in the growth equation: technological progress increases growth, even holding all other inputs unchanged. Higher growth, in turn, is associated with lower volatility.[1] Thus, technological progress impacts indirectly on volatility through its effects on growth. Second, increasing the size of a population increases the level of diversification, but the size of a population is kept in check by the availability of resources in the country.[2] In the Malthusian model, the availability of land is the limiting factor for population increase. Without additional land and given the state of technology, the economy can only support a certain population size at any given time. However, when technological progress occurs, the size of population increases and the economy becomes more diversified, leading to a more stable economy.[3]

(Figure 2 and 3 around here)

[1] See Ramey and Ramey (1995) who find a robust negative association between growth and volatility of growth in the OECD countries and in a sample of 92 non-OECD countries. Similarly, Martin and Rogers (2000) find that standard deviation of annual growth rates is negatively correlated with long-run growth for a panel of industrialized countries. For a critical review of the literature on this linkage, see Döpke (2004).

[2] Population increases can exhaust natural resources and lead to the collapse of the society. De la Croix and Dottori (2008) use a model of population race to account for the tragedy of the Easter Island.

[3] Since the nature of technology is non-rivalry, high population spurs technological progress. Kremer (1993) shows that historically, among societies with no technological contact, those with larger initial populations have had faster technological progress and population growth.

We can visually examine the correlation between scientific research output and growth volatility in Figure 2 and 3. Figure 2 plots the average standard deviation of growth in GDP per capita against the average (logarithmic) number of science and engineering (S&E) publications per (million) capita for all 171 countries in the sample. The diagram shows that, on average, the standard deviation of growth declines as the number of S&E publications increases. Clearly, scientific research output does not explain all the variations in growth volatility in Figure 2, especially in countries with relatively few S&E publications. Bangladesh (BGD), for example, achieved a 0.9 percent standard deviation of growth even though it produced an average of only 1.2 S&E publications per million of population per.[4] In contrast, Figure 3 shows that the correlation between scientific research output and growth volatility is much stronger for high-income countries. The linear regression line in Figure 3 has a simple R-square of 0.244, indicating that 24.4 percent of the total variations in growth volatility can be explained by S&E publications alone. The upshot, as indicated by Figure 2 and 3, is that there exists a strong association between scientific research output and growth volatility for the high-income and possibly middle-income countries, but this association somehow vanishes for low-income countries.

In this article, we hypothesize that slow but steady population increases in high-income developed countries are supported by the creation of new industries and employment opportunities from sustained technological progress. A larger population, in turn, not only spurs further technological progress, but also gives rise to a more diversified economy. In contrast, for low-income developing countries with little technological progress, the Malthusian prediction of "positive check" takes place, where high population growth is coupled with high death rate, and an economy that is highly dependent on one industry or even one commodity. Hence, a larger population may or

[4] One of the factors not directly addressed in this article is technology transfers from the developed to developing countries. Technology transfers can be an important channel for developing countries to achieve stable growth, as shown by the example of the development of garment industries in Bangladesh. Presently, garment industries account for nearly 80 percent of Bangladesh's hard-currency earnings from exports and employ as many as 1.8 million workers. The beginning of garment industries in Bangladesh in April 1980 owes to a joint venture company with the Daewoo Corporation of South Korea, which is a major world textile producer. Daewoo trained workers from the joint venture company in return for royalties and sales commissions to Daewoo (Easterly, 2002, p. 147). If trade is a proxy indicator of technology transfers for low-income countries, our results show some evidence that low-income countries tend to have more stable growth with increasing trade (see Table 4, Column 5).

may not lead to a more stable economy. What is important is whether the population in question has the technological means to diversify.[5]

(Figure 4 and 5 around here)

If technological progress supports increasing population, then scientific research, a natural component of technological progress, should be positively correlated with population size. This is indeed the case in Figure 4, where population size is plotted against S&E publications per (million) capita for the high-income countries. Figure 4 shows that the more S&E publications, the larger the population size. The regression line has a simple R-square of 0.40, meaning 40 percent of the total variations in population size can be explained by S&E publications alone in high-income countries. By contrast, if we plot the same graph for the low-income developing countries, we see hardly any correlation between population size and S&E publications per (million) capita in Figure 5. It appears that the low-income developing countries have not yet reached the level of technological capacity necessary to support population increases and diversification.

The direction of causation between technological progress and growth volatility need to be considered. Although we focus on the effects of technological progress on growth volatility in this paper, the reverse causation from growth volatility to technological progress cannot be discounted. It can be argued that the effect of volatility of the economic system reflects negatively on the level of technological progress by making returns to R&D investments more variable. Consequently, a more stable economy attracts more R&D investments, which increase the level of technological progress, and further reduces volatility via the channels mentioned above. We use the Granger causality framework, which has endured the test of time because of its strong intuitive appeal, to assess the causal relationship between technological progress and growth volatility. Our empirical results show that once we control for other important variables affecting growth volatility and technological progress, the direction of causation is unambiguously running from technological progress to growth volatility, rather than being the other way around or bi-directional.

[5] Acemoglu and Zilibotti (1997) offer an explanation for low-income countries' growth volatility. They argue that the desire to avoid highly risky investments slows down capital accumulation, and the inability to diversify idiosyncratic risk introduces a large amount of uncertainty in the growth process. The typical development pattern will consist of a lengthy period of "primitive accumulation" with highly variable output.

A preview of the results of this study shows that the link between scientific research output and growth volatility is indeed robust, despite using different samples, estimators and control variables. Low-income developing countries, on average, published roughly only one percent of the average number of S&E articles (per million of population per year) of the high-income developed countries.[6] Our estimates from the fixed-effects panel estimations indicate that if the low-income developing countries increase their S&E publications to reach just five percent of the publication level of the high-income developed countries (18.1), their volatility, on average, would roughly be reduced by 2.4 standard deviations, which is a substantial reduction in volatility given that their average volatility for the period 1980-2004 is 3.6 standard deviations.[7] Also, we find evidence to support the hypothesis that increasing population size has different effects on growth volatility, depending on the level of technological progress. Increasing population size reduces growth volatility in high-income developed countries, where scientific research is substantial. However, this effect is exactly opposite in the low-income developing countries, where scientific research is negligible.

This article contributes to the literature by clarifying the nature of technological progress on macroeconomic volatility. On the one hand, technological progress may have a destabilizing effect on the economy by changing the industrial structure and Schumpeterian creative destruction. On the other, as this article argues, technological progress may have a stabilizing effect on the economy through convergence of income, population increases and diversification of the industrial portfolio of a country. Thus, the results of the present study help us identify the role of technological progress in affecting macroeconomic volatility. Another contribution of the present study is that we use scientific research output in S&E publications as a measure of technological progress, rather than the usual TFP growth, which can be associated with GDP growth by construction. Indeed, we are unaware of other studies that examine the effects of

[6] Low-income developing countries published an average of 3.1 S&E articles per million of population per year compared to the average of 362.7 publications per million of population per year for the high-income developed countries over the period 1980-2004.

[7] This is calculated using the estimate from the whole world sample in the fixed-effects panel estimation of the full model. The estimate is -0.486, indicating a 0.00486 reduction in standard deviation for every percentage point increase in S&E publications.

scientific research on growth volatility, especially in using S&E publications as a measure of technological progress.[8]

The organization of this article is as follows: Section 2 discusses previous studies relevant to the topic of technological progress and growth volatility. Section 3 briefly describes recent trends in scientific research in different parts of the world and gives the rationale for using S&E publications as a proxy measure of technological progress. Section 4 discusses the construction of the dataset, and the different samples used in the estimations. Section 5 discusses the results obtained from fixed-effects panel estimations of the baseline and full models, including those of sensitivity checks. Section 6 presents the Granger causality framework and discusses the estimation results obtained from this framework. Section 7 summarizes and makes some concluding remarks.

2. Previous Studies

The idea that technological progress has a stabilizing effect on the economy is not a new one. In 1930, Keynes argued in his essay: *Economic Possibilities for Our Grandchildren* that the absence of modern technology was responsible for the large ups and downs of the standard of living from the earliest times on record to industrialization in the middle of 1700s. More recently, Koren and Tenreyro (2007) provide a theory of technological diversification to explain why GDP is so much more volatile in low-income countries. In their model, production makes use of different input varieties, which are subject to imperfectly correlated shocks. The role of technological progress is to increase the number of varieties, raising average productivity. Also, the expansion in the number of varieties lowers the volatility of output because it provides diversification benefits against variety-specific shocks. Another study by Leung, Tang and Groenewold (2006) builds a simple growth model with endogenous productivity growth and rent-seeking efforts to account for the negative relationship between growth volatility and technological progress.

On the empirical side, we find only a small number of previous studies that examine the specific role of technological progress on growth volatility. A study by

[8] Kerr (forthcoming, 2008) uses ethnic linkage in scientists across different countries to look at the effects of scientific output on trade, employment and productivity growth.

Easterly and Levine (2001) finds that total factor productivity (TFP) growth, a proxy for technological progress, accounts for a substantial inter-temporal and cross-sectional variation in growth. Tang, Groenewold and Leung (forthcoming) find that technological progress is an important stabilizing force of growth volatility and that at least part of the stabilizing force of technological progress originates from strong institutions. Similarly, Tang (2002) shows cross-country evidence of a link between growth volatility and TFP growth. A study by Jones and Olken (2005), which uses the growth accounting framework to decompose growth and a time-series technique to identify the timing of growth takeoffs and collapses, finds that productivity growth (or the Solow residual) is primarily responsible for both growth takeoffs and collapses in a large number of countries.

3. Scientific Research and S&E Publications[9]

High-income developed countries around the world spend an enormous amount of resources on scientific research every year.[10] In the US, for example, R&D spending was approximately US$292 billion in 2003, which was equivalent to 2.7 percent of its annual GDP. This ranks the US as the fifth most R&D intensive country in the world, following Israel (4.9 percent), Sweden (4.3 percent), Finland (3.5 percent), and both Japan and Iceland (3.1 percent). Even less-wealthy, fast-growing developing countries increased rapidly their R&D during the last decade. China, for example, has become the world's third-largest R&D performer, spending $84.6 billion on R&D in 2003. Over the period 1990-2003, China's growth in R&D expenditure averaged 17 percent per annum, compared to 4 to 5 percent average annual growth for the US, the European Union and Japan. On the whole, less-wealthy developing countries' share of world's R&D increased from 7 percent to 16 percent over the period 1990-2003.[11]

---

[9] Information in this section is taken mostly from *Science and Engineering Indicators*, National Science Board (various years).

[10] The term 'science' is used broadly to refer to fields of science such as computer science, life science, earth science, physical science, ocean science and social science.

[11] The majority of R&D spending across countries has been used on development of new and improved goods, services and processes, while basic and applied research account for less than half of the total R&D spending. The US, for example, performed $187.3 billion of development (60 percent), $58.4 billion of basic research (18.7 percent), and $66.4 billion of applied research (21.3 percent). In China, despite its rapid increase in R&D in the last decade, basic research accounts for only 6 percent of its total R&D spending, reflecting China's emphasis of short-term economic development. Similarly, for other high-

S&E publications refer to the total number of articles, notes and reviews published in a slowly expanding set of world's most influential scientific and engineering journals tracked by Thompson Institute for Scientific Information in the Science Citation Index (SCI) and Social Science Citation Index (SSCI).[12] SCI and SSCI give good coverage of a core set of internationally recognized peer-reviewed scientific journals, albeit with some English-language bias. Also, journals of regional or local importance may not be covered, which may lead to some bias against countries with a small and applied science base. The number of journals covered by SCI/SSCI was 4,458 in 1988, 4,601 in 1993, 5,084 in 1998, and 5,315 in 2003. The number of S&E publications covered by SCI/SSCI grew from approximately 466,000 in 1988 to nearly 700,000 in 2003, an increase of 50 percent.

We use the (logarithmic) number of S&E publications, which is a flow variable, as a measure of technological progress. Using S&E publications for measuring technological progress has the following merits. First, publication is a norm in disseminating and validating research results. Major scientific discoveries and breakthroughs are almost always published in influential science and technical journals, whereas patents are predominantly used for minor improvements and modifications of existing products and techniques.[13] Second, publication is crucial for career advancement for researchers in most scientific fields. Third, S&E publications are most commonly used to measure research output in previous empirical studies in the area (see, for example, Crespi and Geuna, 2008). Fourth, S&E publications are increasingly cited by patents, indicating a close linkage between science and technology (the average citations

---

performing Asian economies such as Taiwan, Singapore, South Korean and Japan, basic research accounts for 15 percent or less of total R&D. Development is predominately funded and performed by industry. Microsoft, for example, spent around $6.6 billion in 2006 on development, while IBM and Intel spent $6 billion each, and Cisco Systems and Hewlett-Packard around $4 billion. Most of this money was spent on making small incremental improvements and getting new ideas to market fast. In the US, industry performed 90.2 percent of development with the rest of development performed by federal agencies and universities in 2004.

[12] More detailed information on how the S&E publications are counted among different countries is contained in Appendix A.

[13] The development of "Turbo Codes" gives a good example of the importance of S&E publications as a measure of scientific research. The development of "Turbo Codes" was a fundamental breakthrough in electrical engineering for error correction in data communication, and it provides a scientific method for modern applications such as digital television, 3G mobile telephone and deep-space communication. The technology, which was never patented, was developed in 1993 by a team of French researchers and was published in the Proceedings of IEEE International Communications Conference.

of S&E publications per patent increased from roughly 0.5 to 2 between 1987 and 2004). Fifth, data on S&E publications are collected homogeneously for all countries and from reliable sources. Sixth, there is no possible artificial relationship between technological progress and growth volatility when S&E publications, as opposed to TFP growth, is used to measure technological progress. Seventh, article count is a constituent factor in many country technology indices.

However, as mentioned above, the disadvantage of using S&E publications is that English-speaking countries may be over-represented. The significance of this bias can be checked by using a sub-sample of non-English speaking countries. As will be shown, the negative relationship between S&E publications and growth volatility remains even in the sub-sample of non-English speaking countries.

4. **Data**

This article uses all available data on S&E publications from 1980 to 2004 to construct the main dataset (the whole world). This unbalanced panel dataset has 627 observations from 171 countries. The panel is unbalanced because countries have missing data on S&E publications over the sample period. Observations in the dataset are averages over each five-year interval of 1980-84, 1985-89, 1990-94, 1995-99, and 2000-2004. On average, each country has approximately 3.7 five-year intervals of data. The justification for using five-year intervals is that cross-country averages of a long time span, say 10 to 20 years, are far too long for capturing instability and also an impediment to the study of causality. On the other hand, annual data are too short in duration to reflect the underlying factors. For these reasons, we settle on five-year, non-overlapping intervals.

The dataset for the whole world is further divided into 7 sub-samples. The first sub-sample is called non-English speaking countries, which consists of those countries in the world where English is not an official language. Moreover, we divide the dataset into three different income groups according to the World Bank's classifications. High-income countries are those countries with a gross national income (GNI) of US$11,116 or more in 2006, middle-income countries with a GNI between US$906 and US$11,115, and low-income countries with a GNI of US$905 or less. We further divide the dataset into three different geographic locations according to the World Bank's classifications:

European and Central Asian countries, East Asian and Pacific countries, and sub-Saharan African countries. Appendix B lists all the countries in the samples with their corresponding income group and key country data (averaged over the entire sample period).

The key right-hand-side variable of our regressions is the (logarithmic) number of S&E publications per million of population per year. S&E publications refer to the number of articles published annually from 1980 to 2004 for each of the 171 countries. The raw data indicates that, on average, a country publishes roughly 3,000 articles per year over the sample period. The top five countries in article counts are the US, Japan, UK, Germany and France. In this group, the US led the rest of countries significantly with an average article count of 180,011 publications per year. On the other hand, Antigua, Comoros and Dominica had the least number of publications, averaging no more than one publication per year. We divided S&E publications by the population (in millions) in order to purge the effect of population size on S&E publications. The resulting data show that, on average, a country publishes roughly 100 articles per million people per year over the sample period. The top ten countries, in order, are Israel (1033), Sweden (963), Switzerland (960), Denmark (780), Canada (747), Finland (713), UK (706), US (699), Australia (677), and Netherland (668).

The dependent variable in our regressions is growth volatility. In the literature, the standard deviation of per annum growth rates of real GDP per capita is a widely-used measure of growth volatility. For example, Ramey and Ramey (1995) and Martin and Rogers (2000) both use the standard deviation of GDP growth as a measure of volatility in their cross-country studies of the relationship between business-cycle volatility and growth. Other studies use the interquartile range (the range from the 20th percentile to the 80th percentile of growth), which is less sensitive to outliers and noise in the data, but does not capture any volatility between the two extreme points of the range. In practice, the two measures are highly correlated. Hence, we use the standard deviation of per annum growth rates of real GDP per capita. The average standard deviation across 171 countries is roughly 3.4 percent, indicating that with 68 percent chances, a country's growth rate in a given year would be between plus or minus 3.4 percent from its mean, given the growth rate is normally distributed. The mean GDP growth by country is 1.3

percent. Thus, there is a 68 percent chance that the growth rate of a country would be between -2.2 and 4.7 percent.

In this study, we include a battery of control variables in our regressions to check for the robustness of our regression results. Our goal is to follow closely the current literature in choosing the control variables that have been identified as important in explaining growth volatility. These control variables are initial income, institutional quality (as measured by the degrees of institutional constraint imposed on executive power), GDP growth, total population, manufacturing share of GDP, domestic credit (financial development), trade share of GDP (openness), inflation rate, and government expenditure. Justification for including each of these control variables will be discussed in detail in the next section. Table 2 shows, by country, the basic summary statistics and correlation matrix of all the variables used in the study. The basic summary statistics include mean, standard deviation, minimum, maximum and the number of countries for each variable. To save space, measurements and sources for the control variables are discussed in details in Appendix A.

(Table 2 around here)

The correlation matrix in Table 2 shows the bivariate correlation coefficients among the variables. These correlation coefficients are similar to results obtained from simple cross-country regressions over the entire sample period. First, research output measured by S&E publications is negatively and significantly correlated with growth volatility. This is also true for initial income, executive constraint, GDP growth, population and manufacturing share of GDP. We, however, do not detect any significant correlation between domestic credit (financial development), trade share of GDP (openness), inflation rate and government expenditure on the one hand, and growth volatility on the other. Thus, growth tends to be more stable with higher research output, initial income, executive constraint, GDP growth, population size, and the manufacturing share of GDP. Second, research output is positively and significantly correlated with initial income, executive constraint, GDP grow, manufacturing share of GDP and government expenditure, but is negatively and significantly correlated with the inflation rate. In general, correlation coefficients in Table 2 are consistent with our expectations and the results of cross-country studies in the literature.[14]

The simple correlation coefficients reported in Table 2 do not control for the effects of omitted variables and reverse causation that may be responsible for the observed relationship between the variables in question. To deal with misspecification errors, we opt for the fixed-effects panel estimation, which offers a stringent check on omitted variables. To deal with the issue of endogeneity, we adopt the Granger causality framework. Both of these econometric techniques and their results will be discussed in turn in the next two sections.

5. Fixed-Effects Panel Estimations: Models, Results and Sensitivity Checks

5.1 The Baseline Model and Results

We implement country and time fixed-effects estimations by introducing a dummy variable for each individual country and time period in the samples. On the one hand, the country fixed-effects control for all unobservable time-invariant country specific factors and are appropriate when these unobservable time-invariant factors are believed to be correlated with technological progress. On the other hand, the time fixed-effects control for all unobservable time specific factors that are the same for all countries. Consequently, the fixed-effects panel estimations offer a stringent check against misspecification errors and give a reliable estimate of the link between growth volatility and technological progress.

The fixed-effects panel econometric model is as follows.

$$\sigma_{i,t} = \beta\left(Sci_{i,t-1}\right) + \theta\left(x_{i,t-1}\right) + a_i + u_{i,t} \tag{1}$$

where the subscripts *i* and *t* are country and time indexes, $\sigma_{i,t}$ is the standard deviation of annual growth rates of real GDP per capita and $Sci_{i,t-1}$ is the logarithmic number of S&E publications per million of population lagged one period. θ is a vector of coefficients.

[14] In particular, we find that GDP growth significantly decreases with higher volatility and inflation, but increases with higher executive constraint. These results are consistent with results from empirical studies in the growth literature.

$x_{i,t-1}$ is a vector of time-variant control variables lagged one period, a_i is a vector of unobserved country and time fixed-effects, and u_{it} is an idiosyncratic error. The key parameter of interest in this study is β, which links technological progress to growth volatility. We expect β to be negative and statistically significant at the conventional levels.

(Table 3 around here)

The results of country and time fixed-effects panel estimations for the baseline model are presented in Table 3. The baseline model regresses growth volatility on S&E publications and initial income only without including other time-variant control variables. Initial income is added to the regressions to control for the effect of income levels on growth volatility. It should be noted that the time-invariant mean income differences across countries have already been controlled for by the country fixed-effects. Thus, the effect of initial income in the regressions represents any effect that is above the mean initial income on growth volatility. The estimation results for the whole world are presented first, followed by those of other seven sub-samples in Table 3.

In Table 3, the estimation results show that out of the eight different samples, five of them give a negative estimate, which is statistically significant at the one percent level for S&E publications. The whole world, non-English speaking countries, high-income countries, middle-income countries, and Europe and central Asia all show that scientific research output, as measured by S&E publications, has a statistically negative effect on growth volatility. For example, the estimated effect of S&E publications on growth volatility for the middle-income countries is -0.655, which is statistically significantly at the one percent level. Thus, for the middle-income countries, for every one percent increase in S&E publications, growth volatility is estimated to decrease by about 0.007 standard deviations. To put it in context, if Thailand, a middle-income country that publishes about 8 articles per million of population annually, increases its publications to reach the mean publication level of the middle-income countries, which is about 26 articles per million of population annually, then Thailand’s volatility in growth would be reduced by about 1.6 standard deviations. Thailand, which was the origin of the 1997

Asian financial crises, with an average volatility of 3.1 standard deviations, would be able to reduce its volatility by an half.

Table 3 indicates that the negative effect of S&E publications on growth volatility is statistically significant at the one percent level even for the non-English speaking countries. Consequently, we are confident that the potential bias favoring English speaking countries in article count is not responsible for the observed link between scientific research output and growth volatility. Table 3 also shows that scientific research output does not appear to affect growth volatility at all for samples of low-income countries, East Asia and Pacific, and sub-Saharan Africa. Their S&E publication estimates are positive but statistically insignificant at the conventional levels. As discussed before, low-income countries and sub-Saharan Africa have minimal technological progress, and conduct little, if any, scientific research. Thus, the estimation results are consistent with our expectations that the number of S&E publications of these two samples is too small to have an effect on volatility. However, it is somewhat puzzling to find that East Asia and Pacific, which include some of the fastest growing economies in the world, show an insignificant relationship between growth volatility and S&E. First, East Asian economies had relied heavily on technology transfers for acquiring much of their technological know-how in the initial stage of their development. Second, the results may also reflect that the model of success for East Asia is based on "perspiration rather than inspiration".[15]

5.2 The Full Model and Sensitivity Checks

While we focus on the level of technological progress as a major determinant of growth volatility in this article, other variables can also play a substantial role in explaining the volatility of growth. In this section, we add a number of time-variant control variables to the baseline model to check for the robustness of our earlier results and conclusions. The recent literature is closely followed in selecting the control variables, which will be discussed in turn before estimation results of the full model are presented.

[15] Young (1994), among others, argues that the spectacular postwar growth of East Asia can be attributed almost entirely to these economies' rapid growth in factor inputs rather than in total productivity growth.

In the literature, it has been found that volatility tends to reduce growth. However, the link can also be bi-directional since a steady pace of technological progress sustains a high growth rate and a stable economy. In other words, growth is a channel through which technological progress affects volatility.[16] If this is the case, then adding GDP growth in the regressions should reduce the magnitude and significance of S&E publications in explaining volatility. As a result, we can assess the importance of the growth channel by measuring the amount of reduction of the estimated coefficient of S&E publications after it is added to the regressions.

Institutional quality is another variable that has been studied extensively in the growth literature. A study by Acemoglu, et al. (2003) 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. We believe that technological progress is an important channel through which institutional quality affects volatility. Better protection against expropriation risk from the state and more institutional constraints on chief executive to prevent abuse of power help increase investments in both physical and human capital. Consequently, a better institutional quality stimulates a higher level of R&D investment and technological progress, which eventually leads to a more stable economy. Thus, while a measure of institutional quality by itself is expected to affect volatility significantly in the regressions, its negative impact would be substantially reduced by the addition of S&E publications.

Current literature points to changes in productivity growth rather than factor accumulation as a major determinant of growth reversals and accelerations (Jones and Olken, 2005). Reallocation across sectors, in particular, the higher-productivity manufacturing sectors, is believed to be the mechanism through which productivity growth takes place. We, thus, add the share of manufacturing sector in GDP to the regressions to assess the extent to which the effects of technological progress on volatility are channeled through changes in manufacturing sectors.

At the beginning of this article, we discuss in detail the effects of increasing population size on volatility. An increasing population, when it is accompanied by technological progress, is believed to increase the level of diversification and reduce

---

[16] We are grateful to Daron Acemoglu for suggesting this channel on an earlier draft of this paper.

volatility. Mobarak (2005) finds that an increasing population, which is used as a proxy for diversification, significantly reduces volatility in his empirical study of the effect of democracy on volatility and growth. However, an increasing population can also be destabilizing if it is not accompanied by technological progress, as is predicted by the Malthusian model. Thus, we add total population in the regressions to check the effects of changing population size on volatility.

Although a clear link has not been established in the empirical literature about the effects of trade openness on long-run growth, trade openness has been shown to be growth promoting in the theoretical literature (Frankel and Romer, 1999; Dollar and Kraay, 2003; Wacziarg and Welch, 2003; Rodriquez and Rodrik, 2000). Thus, at least in theory, one can relate trade to volatility through its effects on growth: trade openness promotes growth and thus reduces volatility. In contrast, trade links also imply that business cycle fluctuations are transmitted among trading partners, giving rise to a more volatile economy. A study by Kose, et al. (2006) finds that countries that are more open to trade appear to be able to tolerate higher volatility without adverse consequences for long-run growth. Thus, the effects of trade openness on volatility in the regressions are uncertain empirically.

The next control variable we add to the model is financial development. One school of thought is that more developed financial systems should imply reduced asymmetric information problems, as financial institutions become more capable of identifying projects with a higher probability of failure. Thus, more developed financial systems reduce volatility by reducing credit market imperfections, which amplify shocks to the economy (see, for example, Bacchetta and Caminal, 2000; and Bernanke and Gertler, 1995). Another school of thought believes that financial development reduces volatility because it helps firms facing temporary cash flow or net worth problem to obtain necessary working capital to finance their operations (see, for example, Caballero and Krishnamurty, 2001). Empirical studies by Easterly, et al. (2000); Beck, et al. (2001); Ferreira da Silva (2002); and Raddatz (2006), among others, have confirmed the stabilizing effect of financial development on the economy.

Inflation volatility is an important source of macroeconomic volatility since it increases consumption uncertainty and business risk associated with investments. In the

US, macroeconomic volatility has declined substantially since the middle of 1980s and it has been suggested that the US monetary policy plays an important role in reducing inflation volatility (McConnell and Pérez-Quirós, 2000). Cecchetti, et al. (2006) find that in a broad cross-section of countries, inflation volatility has fallen markedly over the past 20 years due largely to more efficient monetary policy. We thus add inflation in our regressions to account for the effects of changing inflation rates on growth volatility.

Fiscal stabilization policy can mitigate business cycle fluctuations, which are often transmitted among trading partners. Andersen and Spange (2006), for example, show in a two country general equilibrium model that there is a welfare case for an active fiscal stabilization policy, and that it is larger in the presence of rigid wages. We thus add government expenditure in the regressions to consider empirically the effects of changing government spending on growth volatility.

(Table 4 around here)

Table 4 summarizes the results of the full model, which includes in the regressions all the time-variant control variables discussed above, as well as the time-invariant country and time fixed-effects.[17] First, the results show that S&E publications have a negative effect on growth volatility, which is statistically significant at the one and five percent levels for the high-income and middle-income countries, respectively. The magnitude of these samples' estimated coefficients for S&E publications is also much larger than before the control variables are added (-0.651 versus -1.022 and -0.655 versus -0.810). Thus, the result suggests that some control variables (for example, executive constraint) affect growth volatility via S&E publications. However, the estimated negative effect of S&E publications on growth volatility is no longer statistically significant for the samples of the whole world, non-English speaking and Europe and Central Asia. The magnitude of these samples' estimated coefficients for S&E publications is also much smaller than before the control variables are added (-0.486 versus -0.277, -0.543 versus -0.255, and -0.804 versus -0.342). Clearly, the result suggests that some of the effects of S&E publications have been channeled to other intermediating factors (for example, population) in the full model.

[17] Our empirical results include adding control variables independently and sequentially (one by one) to the baseline model. These results are too voluminous to report here, but are available upon request. In general, the unreported results support the main conclusions of this article.

Second, the samples of low-income countries and sub-Saharan Africa show a positive but statistically insignificant estimate for S&E publications. However, we have anticipated this result because the low-income countries and sub-Saharan Africa lack the necessary technological capability to diversify their production. Third, the estimated coefficients for initial income are consistently positive and statistically significant across the different samples, indicating that “extra” increases in income above the average income over time are destabilizing

Estimation results in Table 4 show that population increases have different effects on growth volatility, which are statistically significant. For high-income countries, population increases have a stabilizing (negative) effect on growth volatility, which is statistically significant at the five percent level. However, for low-income countries, population increases have a destabilizing (positive) effect on growth volatility, which is statistically significant at the one percent level. The same contrast is found between Europe and Central Asia and sub-Saharan Africa. For Europe and Central Asia, where technological capability to diversify is relatively high, population increases reduce volatility, but for sub-Saharan Africa, where technological capability to diversify is minimal, population increases exacerbate volatility.

Table 4 shows that GDP growth affects volatility negatively in all but two samples. For low-income countries and sub-Saharan Africa, GDP growth reduces volatility at the five percent significance level. For high-income and middle-income countries, GDP growth still affects volatility negatively, but is not statistically significant at the conventional levels. On the whole, the evidence appears to confirm the current literature on the existence of a negative relationship between growth and volatility.

In Table 4, financial development is estimated to have a stabilizing (negative) effect on volatility for all but two samples. Only the samples of low-income countries and sub-Saharan Africa show a positive estimated coefficient for financial development, but are not statistically significant at the conventional levels. For the high-income countries, financial development reduces volatility at the five percent significance level. The results suggest that the relationship between financial development and volatility may be more complex than what the current empirical literature concludes. Specifically, there are different effects of financial development on volatility, which may ultimately depend on the country's income or institutional quality (see Acemoglu, et al., 2003).

Table 4 shows that reducing the inflation rate increases volatility significantly for the middle-income and low-income countries. These results seem to suggest that for the majority of countries in the world the twin objectives of maintaining steady growth and low inflation at the same time are difficult to achieve: lowering inflation comes at a cost of disrupting the momentum of growth.

The estimation results are mixed for the other control variables in Table 4. First, it shows that fiscal stabilizing policy reduces volatility consistently across different samples, but is effective only for high-income countries. Second, the results for trade openness are mixed, although it significantly increases volatility for the middle-income countries. Third, for high-income countries, the growth of the manufacturing sector helps reduce volatility. Fourth, executive constraint, a measure of institutional quality, has little effect on volatility, which is what we expected since most of its effects have been channeled through other intermediating factors.

In sum, the results of fixed-effects panel estimations show that the effect of scientific research output measured by S&E publications on growth volatility is negative and statistically significant for all samples except low-income countries, sub-Saharan Africa and East Asia and Pacific in the baseline model. In the full model, the statistical significance for the negative relationship between S&E publications and volatility remains for the high-income and middle-income countries, despite adding a battery of time-variant control variables, in addition to country and time fixed-effects, to the regressions. These results provide vigorous and reliable checks on the relationship between scientific research output and growth volatility, suggesting that the negative relationship between the two variables is unlikely to be a product of misspecification errors. In the next section, we will go beyond the fixed-effects panel estimations to look at the issue of causality.

6. The Granger Causality Framework: Models, Results and Sensitivity Checks

In this section, the direction of causation between scientific research output and growth volatility is examined. We employ the Granger causality framework, which has endured the test of time because of its elegance and strong intuitive appeal. The framework tests whether scientific research output "causes" growth volatility or if growth volatility "causes" scientific research output over time. Of course, the causation can be running both ways in which case we would see a bi-directional or feedback relationship between scientific research output and growth volatility. The following bivariate vector autoregression (VAR) is used for the causality testing:

$$
\begin{aligned}
x_t &= \delta_0 + \sum_{i=1}^{m} \delta_i x_{t-i} + \sum_{i=1}^{n} \lambda_i y_{t-i} + \varepsilon_{1t} \\
y_t &= \gamma_0 + \sum_{i=1}^{m} \gamma_i x_{t-i} + \sum_{i=1}^{n} \beta_i y_{t-i} + \varepsilon_{2t}
\end{aligned}
\tag{2}
$$

where x_t and y_t are growth volatility and S&E publications at time *t*, respectively. The bivariate VAR in equation (1) tests causality by implementing the propositions that, first, the future cannot cause the present or the past; second, an event x can only cause y if it occurs before y; and third, the prediction of y can be made more accurate given the occurrence of x. These basic intuitions underline the widely used Granger causality test. The Granger causality framework set out above assumes that the cause contains unique information about the effect, which is exhaustive and not available elsewhere. If the cause and effect are both affected by a third variable, which is not included in the information set underlying the Granger causality test, then the test can be rendered useless. Consequently, we will include those variables that have been found to affect growth volatility directly or indirectly via scientific research output in the last section as a control in the Granger causality test.

An econometric issue arises when the right-hand-side of the regression includes a lagged dependent variable. This is commonly referred to in the econometric literature as the dynamic panel problem. It has been shown that parameter estimates will be inconsistent and biased unless the time dimension of the panel data is very large. Unfortunately, most panel data, including our current data, have substantial sample size in the cross-section dimension, whereas the time dimension is often a single-digit number. The best solution to deal with dynamic panel problem is still a subject of debate in the econometric literature. However, some recent studies (see, for example, Harris and Mátyás, 2004; Kiviet, 1995) that focus on "short and wide" panel data find that the instrumental variable approach pioneered by Anderson and Hsiao (1982) performs as well as any other alternatives. Consequently, we use this method, which requires first differencing all variables and using second-lag differences as instruments. We also follow Arellano's (1989) recommendation by using the twice lagged levels instead of the twice lagged first differences as instruments.[18]

(Table 5 around here)

The length and frequency of the time lags for the Granger causality framework need to be discussed. First, as for the length of the time lags, Granger cautions that 'using data measured over intervals much wider than actual causal lags can also destroy causal interpretation' (Granger, 1987, p. 49). The panel data in this article has five-year periods, which is long enough for studying the effects of scientific research output on growth volatility, and at the same time short enough to allow us to examine the effects of lagged variables and to conduct a Granger causality test. Second, as for the frequency of the time lags, given that our panel has only 5 five-year periods and that the twice lagged levels are used for the instruments, we can only expand the number of lags to *t-2* with substantial reduction in the number of observations and few degrees of freedom.[19] Thus, we have no choice but to constrain the Granger causality test to one lag.

In Table 5, we present results for the tests of whether scientific research output Granger-causes growth volatility. The test results show that all the estimated coefficients for scientific research output are negative, but only those of the high-income countries and Europe and Central Asia are statistically significant at the conventional levels. Thus, scientific research output Granger-causes growth volatility for the samples of high-income countries and Europe and Central Asia, but not for the other samples. Table 5 also shows that last period's growth volatility does not in general Granger-causes current volatility except in the sample of Europe and Central Asia, where a negative inter-temporal causation is detected.

[18] Other empirical studies using Granger causality framework also adopt this approach to deal with the dynamic panel problem. See, among others, Campos and Nugent (2003).

[19] The sample size has been reduced substantially due to differencing of the variables and employing twice-lagged levels as instruments. The whole world sample, for example, has only 285 observations remaining, a reduction of more than 50 percent from the original sample of 627 observations.

(Table 6 around here)

In Table 6, we ask the reverse question of whether growth volatility Granger-causes scientific research output. The test results show that growth volatility does Granger-cause scientific research output for the samples of the whole world, non-English speaking countries, middle-income countries, and Europe and Central Asia. For these samples, the estimated coefficients for growth volatility are negative and statistically significant at the conventional levels, suggesting that increasing growth volatility Granger-causes scientific research output to decrease. Also, the estimated coefficients for scientific research output are positive and statistically significant for all but the samples of Europe and Central Asia and East Asia and Pacific, indicating that increasing scientific research output this period Granger-causes scientific research output to increase next period.

In sum, Table 5 and 6 combined to give a picture that the direction of causation runs uniquely from scientific research output to growth volatility for the sample of high-income countries. For the samples of the whole world, non-English speaking countries, and middle-income countries, the direction of causation runs the other way around, from growth volatility to scientific research output. Europe and Central Asia is the only sample that shows a bi-directional causation. The remaining samples, low-income countries, East Asia and Pacific, and sub-Saharan Africa, do not show any signs of Granger causality relationship between scientific research output and growth volatility.

The Granger causality results shown in Table 5 and 6 can be misleading if there is a “third” variable affecting volatility and scientific research output. We now deal with this potential problem by including in the information set of the test the most likely variables that can affect volatility and scientific research output. From the last section, we have already identified the variables that affect growth volatility directly or indirectly via scientific research output. These variables, in the order of their statistical significance and consistency across the different samples, are population, financial development, inflation, and GDP growth. The results of adding these control variables in the Granger causality test are reported in Table 7 and 8.[20]

(Table 7 around here)

Results in Table 7 show that the addition of the control variables in the Granger causality test increases the statistical significance of scientific research output in explaining growth volatility. Table 7 shows that the coefficients for scientific research output are negative and statistically significant for the whole world, high-income countries, and middle-income countries. Scientific research output, thus, Granger-causes growth volatility for these samples. The remaining samples (except low-income countries) show a negative but statistically insignificant coefficient for scientific research output. In Table 7, population continues to affect growth volatility differently across different samples. For the low-income countries, the effect is positive and statistically significant, but for the samples of the whole world, non-English speaking and high-income countries, the effect is negative but only marginally significant in the case of the non-English speaking countries. Table 7 also shows that GDP growth affects volatility differently across different samples. For the samples of the whole world, non-English speaking countries, middle-income countries and low-income countries, growth increases volatility significantly, whereas for the high-income countries, growth reduces volatility significantly.

(Table 8 around here)

Table 8 shows the results for testing whether growth volatility Granger-causes scientific research output when all the control variables are added. Clearly, all the coefficients for growth volatility are not statistically significant at the conventional levels, indicating there is little evidence that growth volatility Granger-causes scientific research output. There is some evidence, however, that a higher level of scientific research output in a current period leads to a higher level of scientific research output in the next period, especially for the low-income countries and sub-Saharan Africa where the coefficients for scientific research output are both positive and statistically significant. Finally, higher growth appears to lead to a higher level of scientific research output as the coefficients

[20] To keep the regressions parsimonious, we exclude the other control variables, executive constraint, manufacture share of GDP, trade share of GDP, and government expenditure from Table 7 and 8 because these variables have little significant and systematic effects on growth volatility, as indicated by Table 4.

for GDP growth are both positive and statistically significant for the samples of the whole world, non-English speaking countries, and middle-income countries.

In sum, adding the control variables to the Granger causality test reinforces the earlier results that scientific research output Granger-causes growth volatility. Not only do the high-income countries show a uni-directional Granger causation running from scientific research output to growth volatility, the whole world and the middle-income countries also show the same causation after adding the control variables in the test. Moreover, we do not detect any bi-directional Granger causation among the samples. The results suggest that once we account for the variables affecting growth volatility and scientific research output, the link between scientific research output and growth volatility becomes stronger, especially for the high-income countries.

7. Conclusions

This article examines why low-income developing countries have suffered much more growth volatility than high-income, developed countries for the past 40 years. On average, low-income developing countries face three to four times higher volatility than high-income, developed countries, which subject people living in low-income developing countries to constant risk of losing their job, starvation, and even death. What causes more volatile in a country's growth?

We put forward a simple hypothesis to explain the large difference in growth volatility between the high-income and low-income countries: scientific research fuels technological progress and productivity growth, which support population increase, diversification, and stable economic growth. We use S&E publications to measure scientific research output and include all available data from 171 countries between 1980 and 2004 on S&E publications in our samples. In order to check for consistency in our results, the main dataset is further subdivided into seven sub-samples according to different income groups, geographic locations and English as an official language.

We adopt two different econometric frameworks for our investigation: the fixed-effects panel estimation and Granger causality framework. While fixed-effects panel estimation provides stringent checks for misspecification errors, the Granger causality framework checks for reverse causation running from growth volatility to scientific research output. Moreover, using the current literature on growth volatility as a guide, we add a battery of time-variant control variables to the baseline model to check for sensitivity of our results.

Results from the fixed-effects panel estimations strongly support that there is a link between scientific research output and growth volatility: increasing S&E publications tends to reduce growth volatility, and this link is especially strong among high-income developed countries, but disappears for low-income developing countries. Adding a battery of time-variant control variables in the model does not diminish but reinforces the role of scientific research output in reducing growth volatility. The results also show that population increases significantly reduce growth volatility for high-income countries, but for low-income developing countries, population increases exacerbate growth volatility. The evidence thus points to the Malthusian notion of population increases without technological progress as an important contributing factor for low-income countries suffering from large fluctuations of growth.

Results from the Granger causality framework show little evidence of reverse causation from growth volatility to scientific research output once we control for the potential "third" variables affecting growth volatility and scientific research. Specifically, we found strong evidence of uni-directional causation running from scientific research output to growth volatility, especially among high-income developed countries. In our view, high-income, developed countries provide a compelling case for the stabilizing effect of scientific research and technological progress.

Our results complement the literature that finds institutional quality as an important determinant of growth volatility (Acemoglu, et al., 2003). The results show that once we account for scientific research output in the model, institutional quality, which is measured by executive constraint, is no longer statistically significant in explaining growth volatility. Thus, institutional quality works through scientific research and technological progress to affect growth volatility: better institutional quality provides better incentives for investing in both physical and human capital stocks, which enhances scientific research and leads to more technological diversification, steady population increase and stable economic growth.

Overall, the results of this article are consistent with the hypothesis that the lack of technological progress is a first-order problem for stabilizing growth: little scientific research hinders technological progress and productivity growth, which are essential for diversification of industries and creation of new employment opportunities. On the one hand, the lack of diversification magnifies the effects of external shocks on the domestic economy. On the other hand, population increases destabilize the economy when the economy has limited resources and little technological progress to cope with additional population. On both counts, the low-income developing countries are strapped by the rollercoaster of macroeconomic fluctuations.

Figure 1: Growth in GDP per capita (1960-2006) versus GDP per capita (1960)

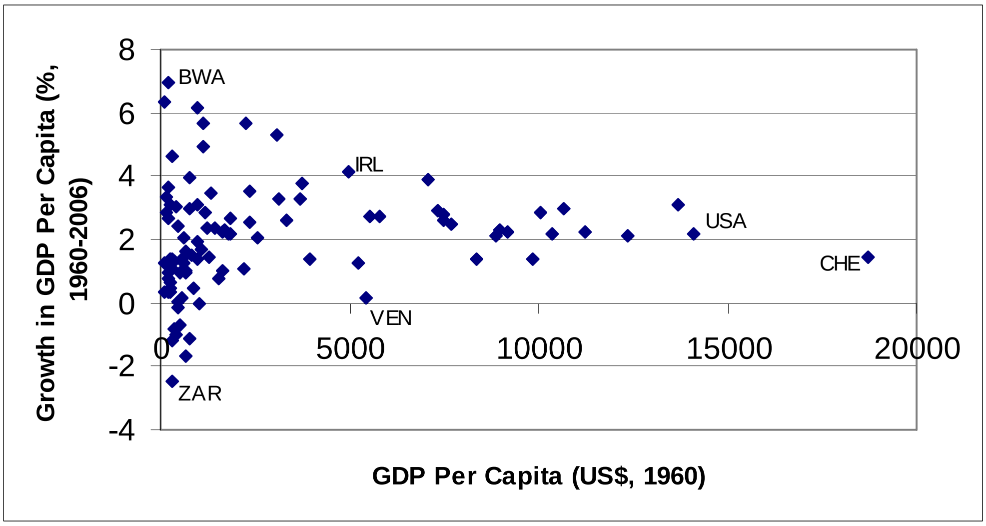

Table 1: Growth Volatility in High-Income OECD Countries and the Rest of the World 1960-2000

	Average standard deviation of real GDP per capita growth rates (%)								
	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	00-04
High-income OECD	0.7	0.6	2.2	1.8	1.8	0.6	0.9	0.4	1.1
Rest of the world	4.6	4.4	5.1	5.4	4.7	4.3	4.5	3.9	3.2

Notes:

1. Standard deviations are calculated from annual percentage growth rates of GDP per capita taken from the 2007 World Development Indicators.
2. There are 25 high-income OECD countries and 146 other countries in the world under the World Bank list of economies (July 2007). See Appendix B for a complete list of countries in the samples.

Figure 2: Scatter Plot of Growth Volatility and Research Output: The Whole World

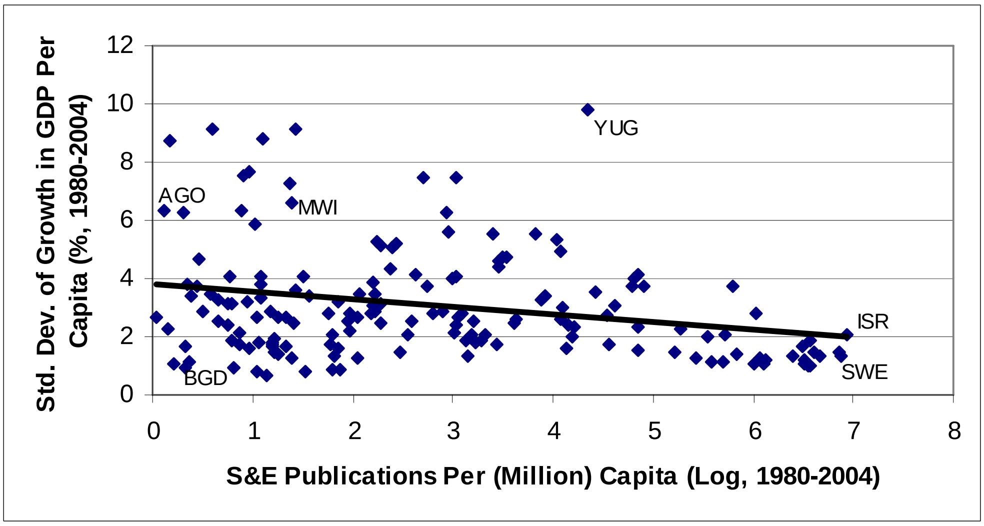

Figure 3: Scatter Plot of Growth Volatility and Research Output: High-Income Countries

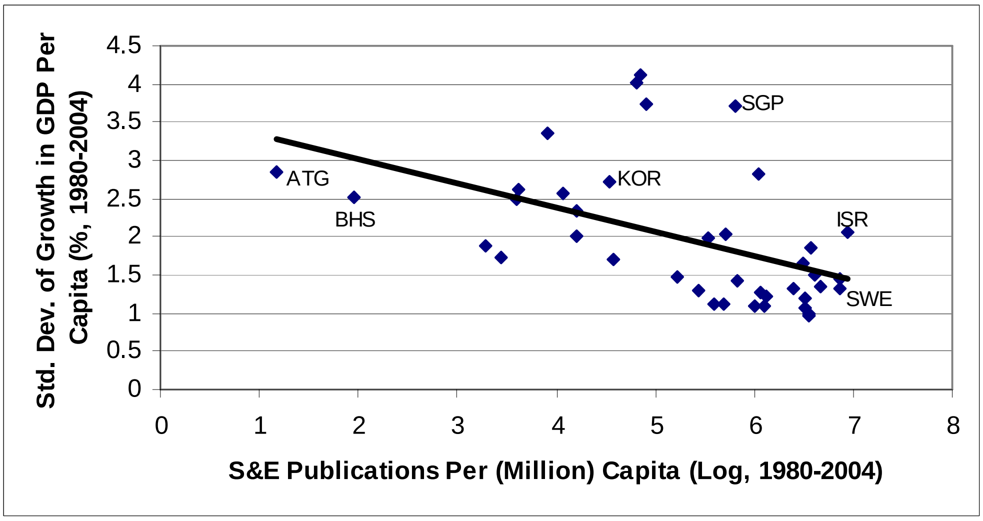

Figure 4: Scatter Plot of Total Population and Research Output: High-Income Countries

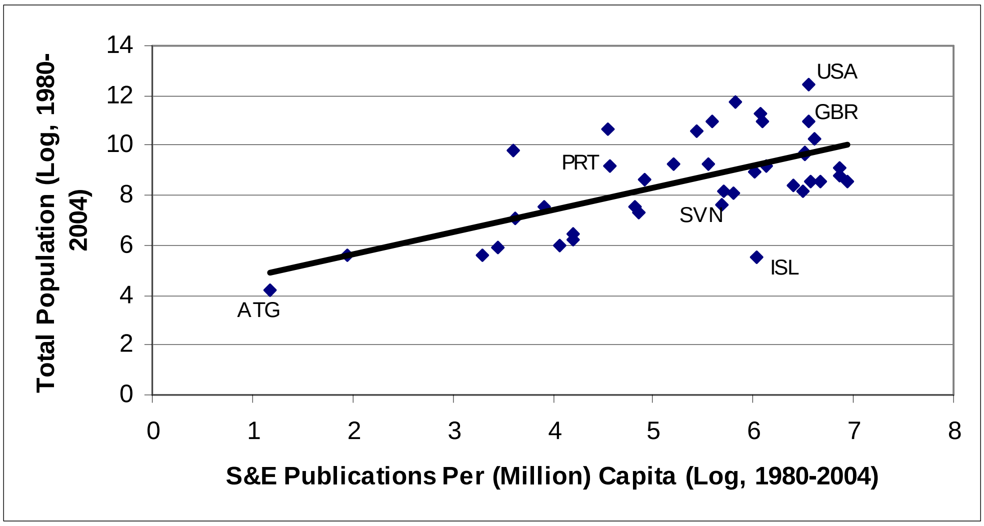

Figure 5: Scatter Plot of Total Population and Research Output: Low-Income Countries

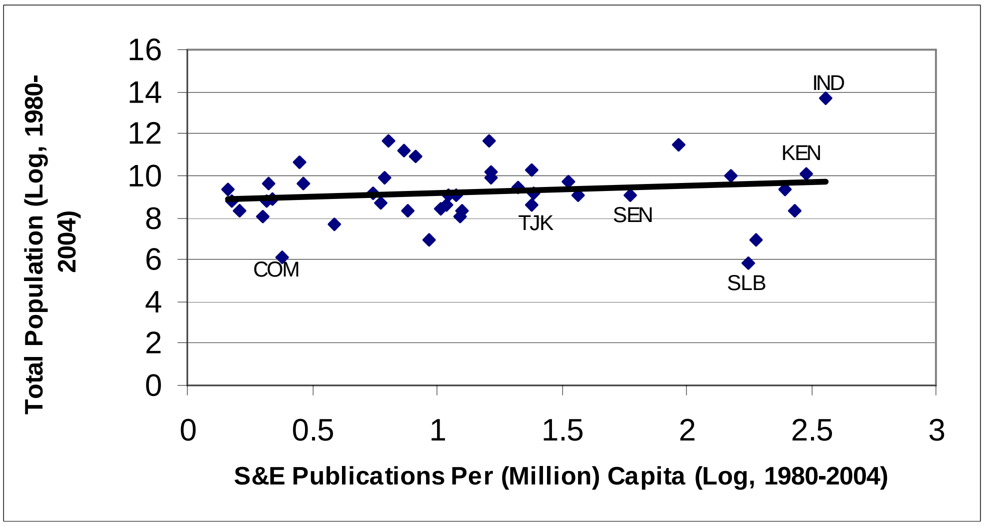

Table 2: Basic Statistics and Correlation Matrix by Country

	Growth volatility (%)	Research output (Log)	Initial income (Log)	Executive constraint (1 – 7)	GDP growth (%)	Pop. (x1000)	Manufacture share (%)	Domestic credit (%)	Trade share (%)	Inflation rate (%)	Govern. expend (%)
Mean	3.405	2.760	7.492	4.502	1.250	33,724	15.42	67.42	79.82	87.86	16.86
St. Dev.	2.930	1.904	1.512	1.962	2.510	118,649	7.28	169.7	42.43	280.4	6.671
Min.	0.687	0.046	4.785	1	-7.41	41.6	0.85	-41.3	14.95	-0.97	4.585
Max.	23.54	6.942	10.40	7	11.08	1,146,983	34.12	2,128	305.7	2,461	52.57
Countries	171	171	171	171	170	169	166	165	167	170	163
Correlation Matrix											
Growth volatility	1										
Research output	-0.275***	1									
Initial income	-0.337***	0.819***	1								
Executive constraint	-0.351***	0.532***	0.566***	1							
GDP growth	-0.186**	0.135*	0.192**	0.282***	1						
Pop.	-0.142*	0.121	-0.101	-0.090	-0.024	1					
Manufacture share	-0.204***	0.434***	0.315***	0.309***	0.117	0.397***	1				
Domestic credit	0.083	0.032	0.010	0.039	0.096	0.054	-0.021	1			
Trade share	0.045	0.101	0.229***	0.049	0.195**	-0.589***	0.045	-0.021	1		
Inflation rate	0.112	-0.142*	-0.183**	-0.131*	-0.343***	0.102	0.046	-0.032	-0.057	1	
Govern. expend	0.033	0.235***	0.236***	0.147*	0.043	-0.416***	-0.188**	-0.028	0.288***	-0.036	1

Notes:
1. Pair-wise correlation coefficients are statistically different from zero at the one (***), five (**) and ten (*) percent levels of significance.
2. Summary statistics and the correlation matrix are calculated from country averages for the time period from 1980 to 2004.

3. Growth volatility is measured by the standard deviation of per annum growth rates of real GDP per capita, in percentage.
4. Research output is the (logarithm) number of scientific and technical publications per (million) capita.
5. Initial income is the (logarithm) level of real GDP per capita in the first year of the sample periods.
6. Initial constraint is constraint on executive power in the first year of the sample periods. 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.
7. GDP growth is the per annum growth rates of real GDP per capita, in percentage.
8. Pop. is total population, in thousands of people.
9. Manufacture share is the value added of the manufacture sector divided by GDP, in percentage.
10. Domestic credit refers to the value of credits provided by banks to the private sector divided by GDP, in percentage.
11. Trade share is the sum of exports and imports divided by GDP, in percentage.
12. Govern. expend is government consumption divided by GDP, in percentage.
13. More detailed descriptions of data and sources are provided in Appendix A. Appendix B provides a list of all sampled countries and their key data.

Table 3: Fixed-Effects Panel Estimations of the Baseline Model

	Research output	Initial income	Country fixed effects	Time fixed effects	No. of countries	Observations
Dependent variable is standard deviations of growth rates of real GDP per capita						
The whole world	-0.486*** (-2.995)	1.2767 (0.910)	Yes	Yes	171	627
Non-English speaking countries	-0.543*** (-2.726)	2.568* (1.855)	Yes	Yes	121	447
High-income countries	-0.651*** (-3.356)	3.022*** (2.726)	Yes	Yes	40	176
Middle-income countries	-0.655*** (-2.728)	1.520 (0.893)	Yes	Yes	86	303
Low-income countries	0.619 (0.986)	-0.619 (-0.195)	Yes	Yes	45	148
Europe & Central Asia	-0.804*** (-3.418)	0.440 (0.285)	Yes	Yes	47	195
East Asia & Pacific	0.200 (0.690)	1.954 (1.327)	Yes	Yes	22	79
Sub-Saharan Africa	0.915 (1.472)	-1.264 (-0.334)	Yes	Yes	44	145

Notes:
1. Independent variables are lagged one time period.
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 two-sided alterative.
4. Detailed descriptions of data series and sources are provided in Appendix A.

Table 4: Sensitivity Analysis: Fixed-Effects Panel Estimations of the Full Model

	The whole world (1)	Non-English (2)	High-income (3)	Middle-income (4)	Low-income (5)	Europe & Cent. Asia (6)	East Asia & Pacific (7)	Sub-Saharan Africa (8)
Dependent variable is standard deviations of growth rates of real GDP per capita								
Research output	-0.277 (-1.257)	-0.255 (-0.703)	-1.022*** (-3.413)	-0.810** (-2.438)	0.631 (0.964)	-0.342 (-0.630)	-0.411 (-0.490)	0.472 (0.710)
Initial income	3.073*** (4.417)	3.955*** (4.554)	3.498* (1.950)	3.799*** (3.932)	4.497*** (2.713)	4.683*** (4.430)	5.154* (1.814)	2.573 (1.299)
GDP growth	-0.043 (-1.216)	-0.049 (-1.058)	-0.141 (-1.580)	-0.055 (-1.510)	-0.216** (-2.329)	0.015 (0.216)	0.203 (0.875)	-0.247** (-2.306)
Executive constraint	0.075 (0.755)	0.160 (1.215)	0.518 (1.247)	-0.071 (-0.424)	0.060 (0.305)	0.531* (1.950)	0.409 (0.764)	0.186 (0.891)
Manufacture share of GDP	-0.027 (-0.651)	-0.059 (-1.034)	-0.142* (-1.768)	0.015 (0.493)	-0.113 (-0.993)	0.008 (0.106)	-0.026 (-0.170)	0.003 (0.024)
Population	-0.671 (-0.407)	-0.462 (-0.209)	-4.508** (-2.265)	2.374 (0.899)	24.908*** (3.647)	-5.350*** (-3.222)	-2.263 (-0.182)	23.010*** (3.635)
Trade share of GDP	-0.005 (-0.842)	-0.011 (-1.094)	0.010 (1.124)	0.026*** (3.019)	-0.023 (-1.178)	-0.006 (-0.458)	0.021 (1.018)	-0.014 (-0.639)
Financial development	-0.003 (-0.523)	-0.009 (-1.214)	-0.015** (-2.176)	-0.010 (-1.614)	0.049 (1.338)	-0.004 (-0.446)	-0.014 (-0.529)	0.028 (1.108)
Inflation	-0.0004 (-1.311)	-0.0004 (-1.266)	0.003 (0.282)	-0.001** (-2.068)	-0.001* (-1.739)	0.0002 (0.126)	0.005 (0.566)	-0.001 (-1.490)
Government expenditure	-0.028 (-0.628)	-0.041 (-0.671)	-0.200** (-2.042)	-0.009 (-0.124)	-0.021 (-0.201)	-0.024 (-0.263)	0.059 (0.224)	-0.146 (-1.503)
No. of countries	157	113	37	79	41	44	15	42
Observations	509	357	121	248	131	131	55	133

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

Table 5: Does Research Output Granger-cause Growth Volatility? Anderson-Hsiao-Arellano IV Estimates of the Baseline Model

	ΔSTD_{t-1}	ΔROP_{t-1}	Country fixed effects	Time fixed effects	No. of countries	Observations
Dependent variable is ΔSTD_t						
The whole world	-0.00001 (-0.428)	-4.850 (-1.519)	Yes	Yes	164	285
Non-English speaking countries	-0.00002 (-0.560)	-3.860 (-0.925)	Yes	Yes	114	205
High-income countries	0.102 (0.333)	-2.960* (-1.846)	Yes	Yes	39	96
Middle-income countries	-0.00001 (-0.346)	-2.389 (-1.082)	Yes	Yes	83	131
Low-income countries	0.00001 (0.398)	-0.329 (-0.123)	Yes	Yes	42	58
Europe & Central Asia	-0.0001*** (-4.826)	-2.228*** (-2.696)	Yes	Yes	45	99
East Asia & Pacific	-0.785 (-1.114)	-7.289 (-0.513)	Yes	Yes	21	35
Sub-Saharan Africa	0.00001 (0.453)	-1.246 (-0.154)	Yes	Yes	43	57

Notes:

1. ΔSTD_t denotes first-differencing of growth volatility between time t and $t-1$, whereas ΔROP_{t-1} denotes first-differencing of research output between time $t-1$ and $t-2$.
2. The results are statistically significant at the one (***), five (**) and ten (*) percent levels, against a two-sided alterative.
3. Detailed descriptions of data series and sources are provided in Appendix A.

Table 6: Does Growth Volatility Granger-cause Research Output? Anderson-Hsiao-Arellano IV Estimates of the Baseline Model

	ΔSTD_{t-1}	ΔROP_{t-1}	Country fixed effects	Time fixed effects	No. of countries	Observations
Dependent variable is ΔROP_t						
The whole world	-0.0001*** (-6.084)	1.170*** (3.582)	Yes	Yes	164	285
Non-English speaking countries	-0.00002*** (-6.027)	1.208*** (2.891)	Yes	Yes	114	205
High-income countries	-0.004 (-0.205)	0.266*** (2.827)	Yes	Yes	39	96
Middle-income countries	-0.00002*** (-4.443)	0.473** (2.049)	Yes	Yes	83	131
Low-income countries	-0.0000 (-1.435)	0.689*** (6.642)	Yes	Yes	42	58
Europe & Central Asia	-0.00003*** (-7.025)	0.104 (0.654)	Yes	Yes	45	99
East Asia & Pacific	0.004 (0.165)	0.341 (0.798)	Yes	Yes	21	35
Sub-Saharan Africa	-0.0000 (-1.030)	1.343*** (3.762)	Yes	Yes	43	57

Notes:

1. ΔSTD_t denotes first-differencing of growth volatility between time t and $t-1$, whereas ΔROP_{t-1} denotes first-differencing of research output between time $t-1$ and $t-2$.
2. The results are statistically significant at the one (***), five (**) and ten (*) percent levels, against a two-sided alterative.
3. Detailed descriptions of data series and sources are provided in Appendix A.

Table 7: Does Research Output Granger-cause Growth Volatility? Anderson-Hsiao-Arellano IV Estimates of the Full Model

	Endogenous variable is ΔSTD_t							
	The whole world (1)	Non-English (2)	High-Income (3)	Middle-Income (4)	Low-Income (5)	Europe & Cent. Asia (6)	East Asia & Pacific (7)	Sub-Saharan Africa (8)
ΔSTD_{t-1}	0.0001*** (3.198)	0.0002*** (3.750)	-0.559 (-1.574)	0.0002*** (3.557)	0.00002 (1.284)	0.047 (0.395)	-0.517 (-0.490)	0.00001 (0.139)
ΔROP_{t-1}	-7.141** (-2.115)	-3.933 (-0.937)	-5.532*** (-2.683)	-4.169* (-1.697)	0.712 (0.040)	-1.571 (-1.356)	-9.034 (-0.260)	-0.627 (-0.057)
ΔIY_{t-1}	-222.24*** (-3.011)	-365.25*** (-3.675)	165.79 (1.343)	-4031.2*** (-2.677)	465.79*** (6.751)	7.201 (0.209)	1342.6 (0.688)	-189.35 (-0.402)
ΔPOP_{t-1}	-539450 (-1.261)	-3200.1* (-1.694)	-795.06 (-0.878)	11244. (1.361)	45281.*** (5.044)	360.25 (0.212)	-3831.0 (-0.198)	272.76 (0.037)
ΔFIN_{t-1}	0.013 (0.972)	0.010 (0.688)	0.142 (0.199)	0.019 (0.814)	0.216*** (3.380)	0.184** (2.367)	-1.087 (-0.290)	0.0004 (0.002)
ΔGR_{t-1}	0.0002*** (4.736)	0.0003*** (4.920)	-0.380* (-1.970)	0.0003*** (4.381)	2.892*** (3.254)	0.047 (0.396)	1.241 (0.474)	-0.857 (-0.909)
ΔINF_{t-1}	-0.0001 (-1.619)	-0.0001 (-1.510)	0.034** (2.356)	-0.0001 (-1.262)	0.018** (2.302)	-0.0001*** (-2.835)	0.016 (0.414)	0.007 (1.491)
Obs.	281	203	95	128	58	99	31	57

Notes:

1. ΔSTD_{t-1}, ΔROP_{t-1}, ΔIY_{t-1}, ΔPOP_{t-1}, ΔFIN_{t-1}, ΔGR_{t-1}, and ΔINF_{t-1} denote, respectively, first differencing of growth volatility, research output, initial income, population, financial development, growth and inflation between time $t-1$ and $t-2$.
2. All regressions include unreported country and time fixed effects.
3. The results are statistically significant at the one (***), five (**) and ten (*) percent levels, against a two-sided alterative.
4. Detailed descriptions of data series and sources are provided in Appendix A.

Table 8: Does Growth Volatility Granger-cause Research Output? Anderson-Hsiao-Arellano IV Estimates of the Full Model

	Endogenous variable is ΔROP_t							
	The whole world (1)	Non-English (2)	High-Income (3)	Middle-Income (4)	Low-Income (5)	Europe & Cent. Asia (6)	East Asia & Pacific (7)	Sub-Saharan Africa (8)
ΔSTD_{t-1}	0.000 (0.125)	0.000 (0.446)	0.014 (0.601)	0.000 (0.059)	-0.000 (-1.371)	-0.008 (-0.297)	0.006 (0.198)	-0.000 (-0.287)
ΔROP_{t-1}	0.437 (1.305)	0.445 (0.977)	0.103 (0.768)	0.053 (0.176)	0.880*** (7.889)	0.025 (0.098)	0.149 (0.162)	2.080*** (7.276)
ΔIY_{t-1}	0.572 (0.078)	2.238 (0.208)	5.041 (0.628)	28.688 (0.157)	-4.459 (-1.106)	-0.897 (-0.117)	-22.126 (-0.428)	-50.002*** (-4.073)
ΔPOP_{t-1}	-13658. (-0.322)	28.343 (0.138)	85.131 (1.446)	556.12 (0.555)	683.55 (1.303)	-30.422 (-0.080)	-779.34 (-1.519)	-535.98*** (-2.786)
ΔFIN_{t-1}	0.0003 (0.229)	0.0006 (0.358)	0.016 (0.353)	-0.001 (-0.203)	0.002 (0.596)	0.002 (0.104)	0.140 (1.411)	0.011** (2.492)
ΔGR_{t-1}	0.00002*** (4.864)	0.00003*** (3.932)	0.0111 (0.886)	0.00002** (2.533)	-0.064 (-1.222)	-0.008 (-0.296)	-0.039 (-0.561)	0.033 (1.356)
ΔINF_{t-1}	0.000 (0.339)	0.000 (0.231)	0.002* (1.911)	0.000 (0.480)	-0.001*** (-2.796)	0.000 (0.151)	-0.0003 (-0.293)	-0.0002* (-1.721)
Obs.	281	203	95	128	58	99	31	57

Notes:

1. ΔSTD_{t-1}, ΔROP_{t-1}, ΔIY_{t-1}, ΔPOP_{t-1}, ΔFIN_{t-1}, ΔGR_{t-1}, and ΔINF_{t-1} denote, respectively, first differencing of growth volatility, research output, initial income, population, financial development, growth and inflation between time $t-1$ and $t-2$.
2. All regressions include unreported country and time fixed effects.
3. The results are statistically significant at the one (***), five (**) and ten (*) percent levels, against a two-sided alterative.
4. Detailed descriptions of data series and sources are provided in Appendix A.

Appendix A: Data and Sources

1. Growth volatility for each economy is measured by the standard deviation of per annum growth rates of real GDP per capita, in percentage over the panel sample periods 1980-84, 85-89, 90-94, 95-99, and 2000-04. Data on GDP per capita (constant 2000 US$) are taken from 2007 World Development Indicators.
2. Research output is the (logarithm) number of scientific and engineering (S&E) publications per (million) capita. S&E articles, notes, and reviews published in a set of the world's most influential scientific and technical journals tracked by Thompson ISI in the *Science Citation Index (SCI)* and *Social Sciences Citation Index (SSCI)*. The number of journals covered by *SCI/SSCI* in 2003 was 5,315. The coverage extends to electronic journals, including print journals with electronic versions and electronic-only journals. Articles are attributed to countries by the author's institutional affiliation at the time of publication. Credit for an article with authors from more than one institution or country is divided among the collaborating institutions or countries based on the proportion of their participating department or institutions. Data are prepared by National Science Foundation and are available from 2007 World Development Indicators. Observations are averages over the panel sample periods.
3. Initial income is the (logarithm) level of real GDP per capita in the first year of each panel sample period. Data on GDP per capita (constant 2000 US$) are taken from 2007 World Development Indicators.
4. Executive constraint is constraint on executive power in the first year of each panel sample period. It measures the institutional and other constraints that are placed on presidents and dictators. It has a scale from 1 to 7, with higher scores indicating more constraints. Score of 1 indicates unlimited authority; score of 3 indicates slight to moderate limitations; score of 5 indicates substantial limitations; score of 7 indicates executive parity or subordination. Scores of 2, 4 and 6 indicate intermediate values. Data are taken from *Polity IV Project: Political Regime Characteristics and Transitions, 1800-2004* prepared by Monty Marshall and Keith Jaggers, Center for Global Policy, http://www.systemicpeace.org/polity/polity4.htm
5. GDP growth is per annum growth rate of real GDP per capita, in percentage. Observations are averages over the panel sample periods. Data are taken from 2007 World Development Indicators.
6. Population is the average total population in logarithm over the panel sample periods. Data are taken from 2007 World Development Indicators.
7. Manufacturing share is the value added of the manufacturing sector divided by GDP, in percentage. Observations are averages over the panel sample periods. Raw data are taken from 2007 World Development Indicators.
8. Financial development is measured by domestic credit. It refers to the value of credits provided by financial intermediaries (banks and non-banks) to the private sector divided by GDP, in percentage. Observations are averages over the panel sample periods. Raw data are taken from 2007 World Development Indicators.
9. Trade share is the sum of exports and imports divided by GDP, in percentage. Observations are averages over the panel sample periods. Raw data are taken from 2007 World Development Indicators.

10. Inflation is the annual percentage change in GDP deflator. Observations are averages over the panel sample periods. Data are taken from 2007 World Development Indicators.
11. Government expenditure is government consumption divided by GDP, in percentage. Observations are averages of the panel sample periods. Raw data are taken from 2007 World Development Indicators.

Appendix B: Key Country Data

1980 – 2004 Average	Std. dev. growth %	Articles per m. capita	Income group H, M, L	Pop. size in 1,000	Private Credit %	GDP growth %	Inflation rate %
Albania	9.1	3.2	M	3124	32.4	1.0	33.6
Algeria	1.6	5.4	M	27265	56.4	0.1	15.2
Angola	6.3	0.1	M	11173	3.0	-0.7	787.3
Antigua	2.9	2.2	H	68	66.7	3.8	4.2
Argentina	5.3	55.7	M	33277	38.6	0.3	317.6
Armenia	3.4	49.1	M	3186	19.4	1.7	527.2
Australia	1.2	676.7	OECD, H	17329	68.1	2.0	4.5
Austria	1.1	406.0	OECD, H	7804	114.1	1.9	2.7
Azerbaijan	7.5	14.0	M	7740	25.4	-2.2	314.5
Bahamas	2.5	6.0	H	262	63.9	0.2	3.5
Bahrain	2.3	66.3	H	519	28.7	1.2	-0.7
Bangladesh	0.9	1.2	L	114336	29.0	2.3	5.3
Belarus	5.0	57.5	M	10074	26.6	1.1	450.9
Belgium	1.2	458.5	OECD, H	10057	100.2	1.8	3.0
Belize	3.9	8.0	M	199	44.8	3.7	2.2
Benin	0.8	1.8	L	5550	17.2	0.2	4.7
Bhutan	1.7	2.3	M	522	4.6	4.8	9.7
Bolivia	1.4	2.5	M	6953	35.8	0.7	847.6
Bosnia	16.8	1.8	M	3715	N/A	N/A	N/A
Botswana	2.1	23.4	M	1543	-41.3	5.5	10.1
Brazil	2.5	23.7	M	152318	89.5	0.7	461.2
Brunei	1.9	25.9	H	267	N/A	-1.9	-1.0
Bulgaria	3.7	119.5	M	8513	38.0	1.9	65.3
Burkina Faso	2.7	1.9	L	9011	9.9	1.2	2.9
Burundi	4.1	1.2	L	5742	23.9	-1.2	9.0
Cambodia	2.3	0.2	L	11018	5.8	5.2	0.9
Cameroon	0.9	5.0	M	12942	20.6	-1.1	3.7
Canada	1.5	747.2	OECD, H	28216	120.1	1.6	3.5
Cape Verde	2.5	0.9	M	372	44.3	2.8	4.9
C.A.R.	4.0	2.0	L	3151	12.9	-1.1	5.0
Chad	8.7	0.2	L	6427	13.5	0.8	3.1
Chile	2.4	63.1	M	13588	87.6	3.5	13.6
China	2.9	8.2	M	1146983	93.1	8.5	5.7
Colombia	2.0	5.1	M	37936	33.7	1.4	19.9
Comoros	3.4	0.5	L	434	17.3	-0.9	4.0
Congo B.	2.8	4.8	M	2635	24.3	-2.9	3.8
Congo Kinshasa	3.7	0.6	L	40115	8.2	-6.0	2460.7
Costa Rica	2.4	19.9	M	3413	27.6	2.2	15.0
Croatia	2.4	125.9	M	4525	60.2	0.5	192.6
Cyprus	2.0	65.7	H	637	137.1	3.0	4.0
Czech Republic	2.0	254.6	OECD, H	10284	61.7	1.0	11.1
Denmark	1.3	779.9	OECD, H	5211	76.7	1.6	3.9
Djibouti	1.8	1.9	M	579	48.4	-4.4	4.2
Dominica	2.7	2.8	M	72	59.6	3.4	4.3
Dominican Rep	3.3	0.9	M	7589	31.7	2.3	21.0
Ecuador	2.6	0.0	M	445552	27.9	0.1	1.2
Egypt	1.3	22.1	M	57437	100.8	2.7	10.5
El Salvador	1.2	0.4	M	5321	36.8	1.9	4.7
Eq. Guinea	15.4	1.9	M	365	28.6	11.1	8.2

Eritrea	6.3	0.4	L	3118	N/A	9.7	5.7
Estonia	4.1	127.9	H	1456	24.4	2.1	63.8
Ethiopia	7.5	1.5	L	55901	38.4	0.3	6.0
Fiji	2.8	21.1	M	742	39.2	1.6	4.3
Finland	1.9	712.9	OECD, H	5027	64.8	2.2	4.2
France	1.1	443.4	OECD, H	56996	103.0	1.7	3.7
Gabon	3.7	14.5	M	1015	23.2	-1.3	3.8
Gambia	2.5	8.8	L	995	13.3	-0.5	11.7
Georgia	6.3	17.9	M	5042	8.3	-2.5	1157.3
Germany	1.3	432.4	OECD, H	80197	115.8	1.7	2.2
Ghana	0.8	3.6	L	17281	24.6	1.9	27.4
Greece	1.5	182.6	OECD, H	10371	91.4	1.4	13.0
Grenada	4.0	3.5	M	95	65.8	4.0	3.7
Guatemala	0.7	2.1	M	9256	29.0	1.1	16.0
Guinea	0.9	0.4	L	6580	6.0	1.1	16.4
Guinea-Bissau	7.7	1.6	L	1083	21.0	-0.4	52.3
Guyana	3.5	6.9	M	733	217.4	2.9	35.7
Haiti	3.8	0.4	L	6999	31.2	-2.5	17.1
Honduras	2.4	1.1	M	5105	36.5	0.2	14.5
Hong Kong	3.7	135.2	H	5731	130.4	4.0	7.1
Hungary	2.3	194.7	M	10392	83.4	1.7	13.3
Iceland	2.8	417.6	OECD, H	259	63.4	1.9	18.0
India	2.1	11.9	L	875943	50.9	3.8	7.7
Indonesia	2.9	0.7	M	189428	45.8	3.5	12.8
Iran	3.0	8.3	M	57359	56.0	1.3	22.5
Ireland	2.0	302.1	OECD, H	3627	72.3	4.5	5.5
Israel	2.0	1033.4	H	5104	112.6	1.7	56.6
Italy	1.1	265.7	OECD, H	56818	91.6	1.7	7.1
Ivory Coast	1.7	2.8	L	13119	36.9	-0.8	4.5
Jamaica	1.8	24.4	M	2427	45.4	1.9	23.7
Japan	1.4	338.7	OECD, H	123447	262.8	2.0	0.9
Jordan	3.2	47.6	M	3862	98.1	0.1	3.7
Kazakhstan	3.1	8.8	M	15439	20.8	0.5	383.0
Kenya	1.5	10.9	L	24408	45.5	0.0	11.0
Kiribati	3.3	2.0	M	76	N/A	1.3	3.1
Korea South	2.7	92.9	OECD, H	43372	71.1	5.6	6.8
Kuwait	4.0	122.0	H	1957	97.7	0.1	5.6
Kyrgyzstan	5.9	1.8	L	4427	N/A	-1.6	137.6
Laos	1.1	0.2	L	4322	8.8	2.8	36.8
Latvia	5.5	44.8	M	2497	18.1	1.6	64.3
Lebanon	5.5	28.8	M	3390	53.2	-6.3	31.5
Lesotho	2.7	2.5	M	1618	11.6	3.1	11.8
Liberia	23.5	1.3	M	2226	453.6	-4.3	255.3
Lithuania	3.0	59.3	M	3574	17.1	-0.2	134.1
Luxembourg	2.6	57.8	OECD, H	399	89.5	3.6	3.3
Macedonia	2.1	19.5	M	1975	52.1	-1.1	166.3
Malawi	6.6	3.0	L	9358	22.8	0.2	26.1
Malaysia	2.9	17.2	M	19945	175.7	3.6	2.8
Mali	3.1	1.1	L	9365	15.6	0.4	4.4
Malta	1.7	30.3	H	366	97.6	4.4	2.7
Marshall IS	4.0	19.0	M	45	N/A	0.0	3.8
Mauritania	3.5	0.8	L	2134	29.7	0.3	9.1
Mauritius	0.8	5.5	M	1083	61.8	5.0	8.1
Mexico	2.7	20.1	M	84948	44.0	1.0	36.8

Micronesia	3.5	8.2	M	99	N/A	-0.1	3.1
Moldova	5.6	18.1	M	4260	24.2	-2.4	162.4
Morocco	4.4	9.7	M	26067	73.8	1.9	3.5
Mozambique	4.7	0.6	L	14637	2127.6	3.4	45.2
Namibia	2.2	6.1	M	1472	43.9	-0.1	11.7
Nepal	1.9	1.2	L	20083	31.8	2.4	10.2
Netherlands	1.1	668.3	OECD, H	15156	122.3	1.7	2.4
New Zealand	1.6	656.2	OECD, H	3539	76.4	1.5	5.7
Nicaragua	1.6	1.6	M	4116	122.0	-1.6	1934.3
Niger	3.8	1.9	L	8997	13.9	-0.5	2.2
Nigeria	2.8	6.1	L	101699	27.5	-0.1	22.7
Norway	1.3	601.9	OECD, H	4305	79.5	2.5	4.7
Oman	2.1	26.9	M	2049	28.0	1.7	1.8
Pakistan	1.8	2.3	L	120134	49.4	2.1	8.9
Panama	2.5	12.3	M	2754	65.7	1.3	2.3
P.N.G.	5.2	10.4	L	4328	31.8	1.6	5.3
Paraguay	2.1	1.4	M	4390	24.4	0.3	19.5
Peru	3.6	3.1	M	23357	19.6	0.6	552.0
Philippines	1.8	2.3	M	66932	50.4	1.0	8.4
Poland	1.5	127.5	M	38368	33.2	3.4	20.6
Portugal	1.7	95.4	OECD, H	10031	97.1	2.4	10.6
Romania	4.4	30.7	M	22570	42.4	0.2	62.6
Russia	3.5	83.2	M	146586	21.8	-0.8	215.3
Rwanda	14.2	1.3	M	6306	14.5	0.4	9.9
Samoa	2.8	15.5	M	164	8.2	1.0	8.6
Saudi Arabia	2.5	35.8	H	17544	58.5	-0.4	1.7
Senegal	1.7	4.9	L	8935	30.0	0.6	3.8
Seychelles	4.1	19.9	M	73	63.9	4.1	2.5
Sierra Leone	8.8	2.0	L	4024	41.3	-4.6	60.0
Singapore	3.7	330.4	H	3281	83.2	4.5	2.1
Slovakia	3.1	100.8	M	5275	34.0	1.4	8.2
Slovenia	1.1	295.3	H	1988	38.3	2.1	36.2
Solomon Islands	5.3	8.5	L	330	33.6	1.5	9.8
South Africa	1.6	61.9	M	36651	119.5	0.0	12.2
Spain	1.3	229.1	OECD, H	39270	106.4	2.3	6.6
Sri Lanka	1.3	5.1	M	17632	39.5	3.3	9.0
St. Kitts	3.2	1.6	M	42	88.2	5.9	4.5
St. Lucia	5.1	8.7	M	137	65.6	3.9	3.1
St. Vincent	3.1	1.2	M	110	57.2	3.1	4.1
Sudan	1.9	2.4	L	27202	18.0	2.1	62.5
Suriname	3.2	5.4	M	405	78.8	-0.1	75.1
Swaziland	1.3	6.8	M	816	15.4	2.4	11.7
Sweden	1.3	962.8	OECD, H	8632	110.6	1.7	4.8
Switzerland	1.4	959.6	OECD, H	6822	163.4	1.0	2.3
Syria	2.4	3.1	M	14353	51.2	1.2	11.0
Tajikistan	7.2	3.0	L	5436	N/A	-7.4	204.8
Tanzania	1.3	3.0	M	29404	20.2	1.1	18.2
Thailand	3.1	8.0	M	57110	120.0	4.9	3.6
Togo	6.3	1.4	L	4137	23.6	-0.2	5.3
Tonga	2.6	6.7	M	94	38.0	1.6	6.4
Trinidad	2.6	36.5	H	1230	58.5	0.1	5.2
Tunisia	1.9	22.0	M	8707	69.5	2.5	4.4
Turkey	4.6	31.0	M	57734	38.0	2.1	56.7
Turkmenistan	9.2	0.8	M	3600	N/A	-4.5	514.1

UAE	3.4	49.0	H	2068	45.3	-2.0	3.0
Uganda	1.5	2.4	L	20402	9.5	2.1	47.2
Ukraine	4.7	33.2	M	50509	23.4	-1.2	338.8
United Kingdom	1.0	705.5	OECD, H	57852	103.3	2.1	5.0
United States	1.0	698.6	OECD, H	257690	165.7	1.9	3.2
Uruguay	4.8	31.9	M	3186	50.2	2.1	43.8
Uzbekistan	2.8	7.8	L	22056	N/A	0.7	195.3
Vanuatu	4.1	12.8	M	157	29.6	-0.5	4.2
Venezuela	7.4	19.6	M	21453	30.3	-0.1	36.7
Vietnam	1.7	1.4	L	70939	16.4	4.8	90.2
Yemen	1.7	0.4	L	14566	42.7	1.3	22.0
Yugoslavia	9.8	77.0	M	9725	49.5	4.8	51.7
Zambia	3.4	3.8	L	8696	54.2	-1.8	66.8
Zimbabwe	5.1	10.0	L	11197	46.9	-1.1	67.2

References

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.

Acemoglu, D. and Zilibotti, F., 1997. “Was Prometheus unbound by chance? risk, diversification and growth.” *Journal of Political Economy*, 105, pp. 1165-200.

Andersen, T. and Spange, M., 2006. “International interdependencies in fiscal stabilization policies.” *European Economic Review*, 50, pp. 1169-95.

Arellano, M., 1989. “A note on the Anderson-Hsiao estimator for panel data.” *Economic Letters*, 31, pp. 337-41.

Bacchetta, P. and Caminal, R., 1996. “Do capital market imperfections exacerbate output fluctuations?” Discussion Paper No. 1422, CEPR, London.

Beck, T., Lundbery, M., and Majnoni, G., 2001. “Financial intermediary development and growth volatility: do intermediaries dampen or magnify shocks?” World Bank Policy Research Working Paper No. 2707.

Bernanke, B. and Gertler, M., 1989. “Agency costs, net worth, and business fluctuations.” *American Economic Review*, 79, pp. 14-31.

Caballero, R. and Krishnamurty, A., 2001. “International and domestic collateral constraints in a model of emerging market crises.” *Journal of Monetary Economics*, 48, pp. 513-48

Campos, N. and Nugent, J., 2003. “Aggregate Investment and Political Instability: An Econometric Investigation.” *Economica,* 70, pp. 533-49.

Cecchetti, S. and Krause, S., 2001. “Financial Structure, Macroeconomic Stability and Monetary Policy, NBER Working Paper No. 8354.

Crespi, G. and Geuna, A., 2008. “An empirical study of scientific production: A cross country analysis, 1981-2002.” *Research Policy*, 37, pp. 565-79.

Cruces, G. and Wodon, Q., 2007. “Risk-adjusted poverty in Argentina: measurement and determinants.” *Journal of Development Studies*, 43(7), pp. 1189-214.

De la Croix, D. and Dottori, D., 2008. “Easter Island’s collapse: a tale of a population race.” *Journal of Economic Growth*, 13, pp. 27-55.

Dollar, D. and Kraay, A., 2003. “Institutions, trade and growth.” *Journal of Monetary Economics*, 50, pp. 133-65.

Döpke, J., 2004. “How Robust is the Empirical Link between Business Cycle Volatility and Long-Run Growth in OECD Countries?” *International Review of Applied Economics*, Vol. 18(1), pp. 103-21.

Easterly, W. 2002. *The Elusive Quest for Growth.* Cambridge, Massachusetts: The MIT Press, pp. 147-52.

Easterly, W., Islam, R. and Stiglitz, J., 2000. “Shaken and stirred: explaining growth volatility.” Annual World Bank Conference on Development Economics.

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

Easterly, W., Kremer, M., Pritchett, L. and Summers, L. H., 1993. “Good policy or good luck? Country growth performance and temporary shocks.” *Journal of Monetary Economics*, 32(3), pp. 459-83.

Ferreira da Silva, G., 2002. “The impact of financial system development on business cycles volatility: cross-country evidence.” *Journal of Macroeconomics,* 24, pp. 233-53.

Frankel, J. A. and Romer, D., 1999. “Does trade cause growth.” *American Economic Review*, 89, pp. 379-99.

Granger, C. W., 1987. “Causal inference.” In: *The New Palgrave: Econometrics*. New York: W.W. Norton.

Harris, M. and Mátyás, L., 2004. “A Comparative Analysis of Different IV and GMM Estimators of Dynamic Panel Data Models.” *International Statistical Review*, 72(3), pp. 397-408.

Jones, B. and Olken, B., 2005. “The Anatomy of Start-Stop Growth.” NBER Working Paper No. 11528.

Kerr, W., 2008. “Heterogeneous Technology Diffusion and Ricardian Trade Patterns.” Harvard Business School Working Paper.

Kerr, W., forthcoming. “Ethnic Scientific Communities and International Technology Diffusion.” *Review of Economics and Statistics*.

Keynes, J. M. 1930. “Economic Possibilities for Our Grandchildren.” In: *Essays in Persuasion*. New York. W.W. Norton & Co., 1963, pp. 358-73.

Kiviet, J., 1995. “On bias, Inconsistency and Efficiency of Various Estimators in Dynamic Panel Data Models.” *Journal of Econometrics*, 68(1), pp. 53-78.

Koren, M., Tenreyro, S., 2007. “Volatility and Development.” *Quarterly Journal of Economics*. 122(1), pp. 243-87.

Kose, M.A., Prasad, E.S. and Terrones, M.E., 2006. “How do trade and financial integration affect the relationship between growth and volatility?” *Journal of International Economics*, 69, pp. 176-202.

Kremer, M., 1993. “Population Growth and Technological Change: One Million B.C. to 1990.” *Quarterly Journal of Economics*, 108(3), pp. 681-716.

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. 159-78.

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

McConnell, M. and Pérez-Quirós, G., 2000. “Output fluctuations in the United States: what has changed since the early 1980’s.” *American Economic Review*, 90, pp. 1464-76.

Mobarak, A. M., 2005. “Democracy, Volatility, and Economic Development.” *Review of Economics and Statistics*, 87(2) pp. 348-61.

National Science Board, various years, *Science and Engineering Indicators*, Arlington, VA: National Science Foundation.

Paxson, C. and Schady, N., 2004. “Child health and the 1988-92 economic crisis in Peru.” World Bank Policy Research Working Paper, 3260.

Pritchett, L., 1997. “Divergence, Big Time.” *Journal of Economic Perspectives*, 11(3), pp. 3-17.

Raddatz, C., 2006. “Liquidity needs and vulnerability to financial underdevelopment.” *Journal of Financial Economics*, 80, 677-722.

Ramey, G., Ramey, V., 1995. “Cross-Country Evidence on the Links Between Volatility and Growth.” *American Economic Review*, 85, pp. 1138-51.

Rodriquez, F. and Rodrik, D., 2000. “Trade policy and economic growth: a skeptic’s guide to the cross-national evidence.” In: Bernanke, B. and Rogoff, K. (Eds.), *NBER Macroeconomic Annual 2000*. MIT Press, Cambridge, MA.

Tang, S.H.K., 2002. “The link between growth volatility and technical progress- cross-country evidence.” *Economics Letters*, 77, pp. 335-41.

Tang, S.H.K., Groenewold, N. and Leung C.K.Y., forthcoming, "The link between institutions, technical change and macroeconomic volatility." *Journal of Macroeconomics*.

Wacziarg, R. and Welch, K.H., 2003. "Trade liberalization and growth: new evidence." NBER Working Paper No. 10152.

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