What do Exogenous Shocks Tell Us about Growth Theories?

October 2007

(This version: December 2008)

Ilan Noy and Aekkanush Nualsri*
Department of Economics
University of Hawaii, Manoa

ABSTRACT

The sources of economic growth and development have been puzzling economists from the modern dawn of the profession. While the Solow-Swan neo-classical model dominated research on growth in the 1960s and 1970s, the 1980s saw the emergence of growth theories that disputed, largely on theoretical grounds, the Solow-Swan assumptions and conclusions. In this paper, we do not examine the determinants of the level of per capita income as an indication that a certain theory has better explanatory power. Rather, we focus on the dynamics of growth following external exogenous shocks (natural disasters). We argue that the data analysis we present suggests that the neo-classical model does not accord very well with the growth experience of developing countries.

JEL codes: O11; O40, Q54
Keywords: growth theory; long run growth; Solow; disasters; exogenous shocks

*We thank participants at conferences in Hong Kong (ACE), and Tokyo and a research workshop at the University of Hawaii for useful comments. Corresponding author: Ilan Noy, Saunders 542, 2424 Maile Way, Honolulu, HI 96822. Noy: noy@hawaii.edu; Nualsri: aekkanus@hawaii.edu.

1. Introduction

The sources of economic growth and development have been puzzling economists from the modern dawn of the profession; or at the very least from Adam Smith's (1776) *An Inquiry into the Nature and Causes of the Wealth of Nations*. Current research into the question of growth originates from the seminal contributions of Solow (1956) and Swan (1956). While the neo-classical Solow-Swan theory had dominated theoretical and empirical research on growth in the 1960s and 1970s, the 1980s saw the emergence of growth theories that disputed the Solow-Swan assumptions and conclusions. These new growth theories look in more detail into the sources of endogenous technological change.[1]

While not necessarily exclusive, with some contributions synthesizing ideas from more than one set of models, this division spawned an active empirical literature that has attempted to determine the validity of these different approaches to the question of growth. It is to this literature that we aim to contribute. We focus on describing the dynamics of growth following external exogenous shocks (natural disasters) and attempt to derive conclusions from these dynamics regarding the applicability of these competing paradigms.

The empirical research into the sources of growth and into the debate between the neo-classical and the endogenous technological change approaches started in earnest with the path-breaking work of Barro (1991). Barro's work was quickly joined by Mankiw et al. (1992), with both arguing that the neo-classical Solow-Swan model augmented with human capital is adequate in explaining a large part of the distribution of income across countries. Other notable contributions supporting the neo-classical framework that

[1] e.g. Romer (1986, 1990); Lucas (1988); Aghion and Howitt (1992), to name only a few.

appeared later in response to skepticism about the early results are Barro et al. (1995), Jones (1995), Sala-i-Martin (1997) and Sala-i-Martin et al. (2004).

Empirical work differing from the neo-classical view largely belongs to two camps. The skeptics argue that most of the results in the empirical growth literature are not robust. In particular, Levine and Renelt (1992) argue that the only robust result is a correlation between investment and growth, Durlauf et al. (2008) find that the only robust correlates of growth are macro-economic policy and unknown time-invariant country-specific characteristics, while Minier (2007) identifies fiscal policy as the only robust influence on growth. Doppelhofer and Weeks (2007) argue that previous research ignores the joint-ness of the various identified growth determinants and that this lacuna introduces a bias to all previous empirical work and casts doubts on all their conclusions.

The second strand argues that certain descriptions of the data fit the alternative models much better than the neo-classical framework. In this vein, Bernanke and Gurkaynak (2001) argue that the observed degree of correlation between saving and growth cannot be explained by the neo-classical model (in which long-run growth is independent of the saving rate). This observed relationship, together with other characteristics of total factor productivity (TFP), lead them to conclude that endogenous growth models fit the data much better.[2] In a more recent contribution, Farmer and Lahiri (2006) construct a two-sector open-economy AK model and show that it fits some moments of the data much better than the Solow-Swan model.[3] Howitt (2000) constructs

---

[2] In a related paper, Aghion et al. (2006) construct a model that emphasizes the links between domestic saving and technological catch-up through foreign direct investment. The authors argue that only this open-economy model fits various empirical regularities they identify in the international saving-growth correlations.

[3] An open-economy version of the Solow-Swan model will generate similar predictions to the closed economy version but a more rapid convergence to the steady-state.

an endogenous growth model that relies on Schumpeterian creative-destruction; and with the support of data analysis concludes that this model also has superior explanatory power to the neo-classical one.[4]

Almost all of this body of empirical research assumes that countries have reached their steady states and derives its conclusions regarding the validity of the various theories based on this assumption. In addition, most estimations following Mankiw et al. (1992) also assume a constant technological growth rate across countries; see McQuinn and Whelan (2007a and 2007b) for a recent discussion of this problem and ways to circumvent it.

In this paper, we do not examine the determinants of the level of per capita output or capital as an indication that a certain theory has better explanatory power. Rather, we focus here on the dynamics of growth following an external shock. The main advantage of this emphasis is that we no longer need to assume that countries have already reached their steady state or that productivity is similar across countries, given levels of capital and labor. Indeed, our results are valid whether countries have already reached their steady state or in cases where they are still very far from this steady state on the transition path.

Empirically describing the typical dynamic response of the economy to an exogenous shock, we argue, makes many of the growth theories previously proposed falsifiable (as in Popper, 1959). We conclude that the data we present, subject to the

---

[4] A different set of papers skirts the division between the neo-classical and the endogenous frameworks to examine a whole set of country characteristics which it deems to determine the fundamental potential for growth. Some of the more widely cited works within this literature are: Persson and Tabellini (AER, 1994), Easterly and Levin (QJE, 1997), Sachs and Warner (AER, 1997), Rodrik (JEG, 1999), Acemoglu et al. (AER, 2001), and Alesina et al. (JEG, 2003).

caveats we detail in the last section, suggests that the standard neo-classical models generally do not accord very well with the growth experience of developing countries. Our framework, however, does not allow us to differentiate among certain types of endogenous growth theories that appear to be consistent with our empirical evidence.

The next section describes what may be the growth response of an economy to an exogenous shock, while sections 3 and 4 discuss the methodology and data, section 5 describes our results and section 6 concludes and discusses some caveats.

2. The Impact of Disasters on Output Growth

In order to be able to identify anything about the growth transition, we first need to identify a set of exogenous shocks and describe the average reaction of an economy to these shocks. We are particularly interested in the negative shocks to the stock of physical and human capital. Our empirical examination uses compiled data on natural disasters as proxies for these shocks. The assumption of exogeneity of natural disasters is both intuitive, empirically supported (Noy, 2008) and in line with the three other previous papers that also use disaster measures as exogenous shocks: Raddatz (2007) uses the number of large disasters, per year, that are recorded in the EM-DAT dataset; Skidmore and Toya (2002) use the frequency of disasters (the number of disasters occurring over the period 1960-1990) as their disaster variable in a cross sectional dataset; and Ramcharan (2007) uses a binary indicator for whether a disaster occurred in the any country-year observation.

The skepticism about possible interrelationship between economic growth and the severity of natural disasters, if there was any, is undermined by our use of a 5-year growth average rather than a long term cross-section since the likely impact of macroeconomics on the depth of the disaster is through GDP levels rather than the 5-year growth rate averages. For example, building codes, efficient evacuation procedures, availability of shelters, etc. will all be more readily available in countries with higher incomes rather than countries with a recent higher growth rate.

2.1 Theory Predictions

The likely impact of natural disasters on growth dynamics varies from one theory to the next. Standard neo-classical frameworks that view technical progress as exogenous, e.g. the Solow-Swan model with exogenous saving rates[5] and the Ramsey-Cass-Koopman model with consumer optimization[6], all predict that the destruction of capital (physical or human) will enhance growth since it will drive countries away from their balanced-growth steady states. In such a case, the loss of capital caused by natural disasters will lead to more rapid capital accumulation and thus to higher temporary growth until the economy reverts back or reaches its steady state. In appendix C, we provide an example of the Solow-Swan model augmented with human capital and show that the partial derivative of output growth with respect to the level of capital stock is negative.

Endogenous growth frameworks do not suggest such clear-cut predictions with respect to output dynamics depending on the approach used to explain the endogeneity of technological change. For example, models based on Schumpeter's creative destruction

[5] Solow (1956) and Swan (1956)
[6] Ramsey (1928), Cass (1965), and Koopman (1965)

process[7] may also ascribe higher growth as a result of negative shocks (Hallegatte, 2006), as these shocks can be catalysts for re-investment and upgrading of capital goods. These shocks may also be catalysts for adoption of new technologies that may be beneficial in generating (especially long-term) growth.

On the contrary, the AK-type endogenous growth models in which the technology exhibits constant returns to capital predict no change in the growth rate following a negative capital shock. However, the economy that experiences a destruction of the capital stock will never go back to its old growth trajectory.

Endogenous growth models that have increasing returns to scale production generally predict that a destruction of part of the physical or human capital stock results in a lower growth path and consequently a permanent deviation from the previous growth trajectory. Romer (1990)'s model of endogenous technological change, for example, concludes that the growth rate is increasing in the stock of human capital. A reduction in the total stock of human capital will lower the amount of human capital devoted to the accumulation of knowledge and technology which will ultimately retard economic growth.

A two-sector endogenous growth model in the Uzawa-Lucas framework[8] yields different implications for economic growth. Under this framework, transitional growth rates are determined by imbalances between physical and human capital. Economic growth rates are likely to increase when natural disasters relatively damage the physical

[7] Schumpeter (1934)
[8] Uzawa (1965) and Lucas (1988)

capital stock. On the opposite, when human capital accumulation is mainly affected, the growth rates are likely to fall.[9]

2.2 Related Empirical Work on Disasters and Exogenous Shocks

Using a household panel dataset, Dercon (2004) finds that rain fall events in rural Ethiopia have a long-term negative and persistent effect on household consumption; and no reversion back to a pre-disaster trend. Abadie and Gardeazabal (2005) develop and estimate a model of a small open economy that is impacted by an exogenous terrorist event. These events have a negative impact on the economy through destruction of the capital stock, an increase in the perception of uncertainty, increases in defensive expenditures that draw resources from more productive sectors, and an impact on specific industries such as tourism. Each of these may also be applicable in the case of a large natural disaster. Abadie and Gardeazabal (2005) follow their model with an estimation of the effect of terrorism incidents on capital flows (specifically foreign direct investment). They find that even events that induced only a small reduction in the capital stock resulted in large and economically meaningful shifts in foreign direct investment decision.

Horwich (2000) argues that natural disasters may have no impact on economic growth if the amount of capital that is destroyed is negligible relative to the amount of capital available for production. He notes that even the impact of the Kobe earthquake, one of the most costly disasters ever, was minimal since only 0.08% of the Japanese capital stock was destroyed. In a different context, Davis and Weinstein (2002) and

[9] For more details and comprehensive discussion, see Barro and Sala-i-Martin (2003), chapter 5.

Miguel and Roland (2006) find that the war time bombing of Japan and later Vietnam had relatively little long term impact on development in the targeted regions. [10]

3. Data

We follow of Islam (1995) and Barro and Sala-i-Martin (2003) by using panel data in which the entire sample period is divided into several shorter time intervals.[11] We opt not to use yearly data in order to remove influences associated with business cycles. For convenience, we choose to rearrange annual data at 5-year periods as most data on years of schooling and fertility rates are available only at 5-year frequencies. Our panel data covers 98 countries, developed and developing over the five 5-year intervals 1975-79, 1980-84, 1985-89, 1990-94, and 1995-99.

As discussed above, we assume natural disasters should be viewed as strictly exogenous shocks to the economy. We construct two different measures of exogenous shocks—human and physical capital shocks. Human capital, by definition, refers to the stock of productive skills and technical knowledge embodied in human labor. We assume a positive relationship between an adverse effect on human capital stock and loss of life due to natural disasters. Accordingly, our data series on human capital shocks originates from compiled data on disaster-related deaths. For physical capital shocks, we use data on reported property damages from natural disasters.

The raw data on natural disasters are from the EM-DAT database collected by the Centre for Research on the Epidemiology of Disasters (CRED) at the Catholic University of Louvain in Belgium. The EM-DAT database is compiled from various sources

[10] These papers use cross sectional estimation by country/province, and examine the very long term impact of the US bombings several decades later.
[11] More recent examples are Barro and Lee (2005), Beck and Levine (2004), and Durlauf et al. (2008).

including UN agencies, non-governmental organizations, insurance companies, research institutions and press agencies. It contains cross-country data on the occurrence and effects of natural disasters, including number of people killed, number of people affected, and property damages. A natural disaster is defined as a natural event which overwhelms local capacity, necessitating a request for assistance from national or international levels. To be specific, at least one of the following criteria must be fulfilled: (1) 10 or more people reported killed; (2) 100 people reported affected; (3) declaration of a state of emergency; or (4) call for international assistance.[12] These disasters can be hydro-meteorological, geophysical, or biological.[13]

We aggregate the disaster data on an annual basis to begin with. We control for the size of the economy by measuring the number of deaths as a ratio of country's population and measuring the damages as a ratio of country's GDP. Then, we sum up the annual ratios to fit our 5-year interval framework. We name our new data series on human capital shocks (deaths) and physical capital shocks (property damages) as KILL and DAMAGE, respectively.[14]

We are concerned about the accuracy of disaster data. Our estimation methodology deals with the issue in two ways: First, any time-invariant country-specific measurement error is absorbed in the country fixed effects. Second, the bias arising from time-variant error is mitigated by our use of lagged variables as instruments in the two-step GMM. In Table 1, we provide descriptive statistics on our disaster measures. Natural

[12] The number of people killed includes "persons confirmed as dead and persons missing and presumed dead."
[13] Hydro-meteorological disasters are, for example, floods, wave surges, storms, droughts, landslides, and avalanches. Geophysical disasters include earthquakes, tsunamis, and volcanic eruptions. Biological disasters refer to epidemics and insect infestations (the last category is very rare in our data).
[14] We do not use the disaster frequency measure favored by Skidmore and Toya (2002) because this measure conveys no information about the magnitude of the disaster shock. A frequency measure is probably more closely correlated with future likeliness of disaster occurrence.

disasters in OECD (developed) countries apparently constitute less severe exogenous shocks, both in terms of deaths and damages, than those in non-OECD (developing) countries. It is probably because a high-income country is relatively more capable of preventing and mitigating the risk to life and property from natural disasters.

The dependent variable in our growth regression is the 5-year average growth rate of real GDP per capita. The set of explanatory variables consist of our measures of exogenous shocks along with other standard growth determinants which we group into two categories: initial condition and control variables. The initial condition variables (income and schooling), accounting for the existing level of physical and human capital, are measured at the beginning of each five-year period. The control variables (fertility rate, investment, government consumption, and openness) are recorded as five-year averages. The list of countries included in the dataset is provided in appendix A and the definitions and sources of variables are provided in appendix B.

4. Estimation Methodology

We use panel fixed-effects and generalized method of moments (GMM) estimation methods; instead of relying on the cross-sectional datasets that are sometimes used in the growth literature. Using panel estimation highlights several advantages over a conventional cross-section. It utilizes more information, mitigates the problem of multicollinearity in time-series, and most importantly in the context of growth regressions, reduces the estimation bias induced by the time-invariant omitted variables. As documented in Islam (1995), a single cross-country growth regression suffers omitted variable bias because the country-specific technical efficiency is unobservable. This unobservable technical efficiency is also likely to be correlated with other growth determinants such as education and investment. In such a case, a standard least-squares estimator from cross-sectional data will not only be inefficient but also biased and inconsistent. Panel estimation methods, on the other hand, offer ways to control for unobservable time-invariant effects and hence give more reliable estimates.

4.1 Fixed-Effects Model

In their comprehensive empirical work on growth, Sala-i-Martin et al. (2004) find 18 variables that are 'robustly' correlated with per capita GDP growth. Out of these, 11 are time invariant and most of the others are also very slow to change over time. This suggests a strong justification for a country-effect specification in our work. We employ the Hausman (1978) specification test under the null hypothesis of unbiased random-effect estimator. Not unlike previous work, we easily reject the null which suggests that the fixed-effects model is the appropriate one.

We consider a cross-country growth regression with unobservable, time-invariant, country-specific effects:

(1) $$g_{it} = \beta' X_{it} + a_i + u_{it} \text{ for } i = 1,\ldots,N \text{ and } t = 1,2,\ldots T$$

where g_{it} is real per capita GDP growth rate, X is the set of explanatory variables including our measures of exogenous shocks, a_i is a time-invariant unobservable country effect which represents initial technical-efficiency, and u_{it} is the error term.

*4.2 Generalized Method of Moments (*GMM)

In addition to using fixed-effects model, we also employ the Arellano and Bond (1991) generalized method of moments (GMM) approach to handle the issues of endogeneity and mis-measurement which have been considered problematic within the empirical growth literature. The GMM approach is very appealing to our work for several reasons: It eliminates unobservable, individual fixed-effects by differencing, thus taking away the bias owing to the omission of country-specific technical efficiency. The GMM estimation also allows us to address the problem of potential endogeneity of the right-hand-side variables in the growth equation by employing instruments. Finally, the use of instrumental variables also helps reduce the incidence of bias due to mis-measurement.

For this context, there are two major types of GMM estimators: "difference GMM" and "system GMM". We perform and report results from both. Consider a cross-country growth regression of the following form:

(3) $$y_{it} - y_{it-1} = \delta y_{it-1} + \beta' X_{it} + a_i + u_{it} \text{ for } i = 1, \ldots, N \text{ and } t = 2, \ldots, T$$

where y is the logarithm of real per capita GDP (y_{it-1} represents previous end-of-period income), a_i is a time-invariant unobservable country effect, X is the set of explanatory variables that are potentially endogenous and correlated with a_i , and u_{it} is the error term.

The GMM approach deals with possible bias caused by country-specific fixed effects by first-differencing:

(4) $$(y_{it} - y_{it-1}) - (y_{it-1} - y_{it-2}) = \delta(y_{it-1} - y_{it-2}) + \beta'(X_{it} - X_{it-1}) + (u_{it} - u_{it-1})$$

for $i = 1, \ldots, N$ and $t = 3, \ldots, T$

However, the new error term of equation (4), $(u_{it} - u_{it-1})$, violates the independence assumption as it is now correlated with the lagged dependent variables, $(y_{it-1} - y_{it-2})$. Arellano and Bond (1991) propose a two-step difference GMM approach to yield a consistent estimator by applying the moment restrictions:

(5) $$E\left[y_{it-s}\Delta u_{it}\right] = 0 \text{ for } i = 1,\dots,N \text{ ; } t = 3,\dots,T \text{ and } s \geq 2$$

(6) $$E\left[x_{it-s}\Delta u_{it}\right] = 0 \text{ for } i = 1,\dots,N \text{ ; } t = 3,\dots,T \text{ and } s \geq 2$$

The moment conditions in (5) and (6) imply that one can use lagged values of y_{it} and x_{it} dated t-2 and up as instruments for the equation in first-differences.[15] Moreover, even in the presence of measurement errors in the predetermined variables (or strictly exogenous variables), the lagged levels of the observed series date *t-2* and further back (or date *t-1* and back) can still be used as instruments. Provided that there is no second-order serial correlation in the differenced error term, the two-step difference GMM estimator is consistent.

Nonetheless, the two-step Arellano-Bond GMM estimator encounters a finite sample bias particularly when the lagged levels are only weakly correlated with the subsequent first-differences. Arellano and Bover (1995) and Blundell and Bond (1998) propose a ‘system GMM’ estimator which they show has superior finite sample properties. A system of two equations is built--the level equation and the differenced equation by exploitation of the moments in (5), (6) and additional moments as in (7) and

[15] In the case that x_{it} is predetermined but not strictly exogenous, the lagged value date *t-1* is also valid; if it is strictly exogenous, then all the x_{it} are valid instruments.

(8) which imply the validity of lagged first differences as instruments for equations in levels.[16]

(7) $$E(u_{it}\Delta y_{it-1}) = 0 \text{ for } i = 1,\ldots,N \text{ and } t = 3,4,\ldots,T.$$

(8) $$E(u_{it}\Delta x_{it-1}) = 0 \text{ for } i = 1,\ldots,N \text{ and } t = 3,4,\ldots,T.$$

5. *Results*

5.1 Fixed-Effects Model

Table 2 reports estimated coefficients, robust standard-errors, and the Hausman statistic for the rejection of the random-effects model. Our benchmark specification (table 2 column 1) is equivalent to Skidmore and Toya's (2002) cross-sectional study on the long-run effect of disasters.[17] Of all the explanatory variables, we find that initial income and investment ratios are statistically very significant i.e. lower initial income and higher investment as a share of real GDP are associated with an increase in per capita output growth.[18]

The next few specifications in table 2 turn to our variables of interest (column 2-3) while maintaining the same full sample. Interestingly, these results are in contrast with the predictions of the neo-classical growth theory. Under the neo-classical growth paradigm, the destruction of capital will push the level of capital further away from its steady-state balanced growth path, which in turn accelerates the rate of growth of capital

---

[16] However, it should be noted that the additional moments require strict assumptions that the first-differences are not correlated with fixed effects and that the initial conditions, y_{i1}, satisfy the mean stationary restriction for each individual.

[17] The disaster variable in Skidmore and Toya (2002) is the frequency of disasters a country experiences; we employ different measures of natural disasters.

[18] The negative coefficient for initial income is very robust to all specifications and estimation techniques. This appears to support the 'convergence' hypothesis.

and output along its transitional path. We, however, find no supporting evidence. Our estimated coefficient for physical capital shock is positive but statistically indistinguishable from zero. We do, however, find that a negative shock to human capital lowers per capita output growth (this result is statistically significant).[19]

The last four columns in Table 2 report the same specifications for two sub-samples: OECD (developed) and non-OECD (developing) countries. From these, we conclude that the average impacts of the negative exogenous shocks on growth dynamics are of different magnitudes, and sometimes different directions, between developed and developing countries. In the non-OECD group we find strong support for growth deceleration following a negative shock to human capital, but for the OECD group neither shock variable has any easily identifiable impact. One plausible explanation is that natural disasters are no longer a serious threat to life and property for the OECD countries; probably due to their effectiveness in disaster prevention, mitigation and preparedness. Unfortunately, to clarify this point one needs different measures of ex-ante physical disaster intensity data (such as land coverage, storm circumference, etc.). Thus, based on our empirical evidence alone, no conclusion can be drawn on the validity of growth theories for the OECD countries. For the non-OECD countries, we do find evidence of growth reduction following an exogenous shock for the simple version and methodology used in table 2.

5.2 GMM

[19] A failure to find any result may also be due to the fact that we control for investment. However, the negative results we consistently find for the KILL variable suggest that indeed the patterns we observe are not well-explained by the neo-classical model.

Table 3 and Table 4 report the regression results from two-step difference and two-step system GMM estimates, including estimated coefficients, and Windmeijer's finite-sample corrected robust standard errors. We also report two test statistics: the Arellano-Bond test for AR(2) in first differences and the Hansen test for over-identifying restrictions. Failure to reject the null hypotheses in both provides qualified support for the model. We take into account some possible mis-measurements in our exogenous shock variables by instrumenting with their lagged levels. We find that the estimated coefficients for exogenous shocks and their significance do not vary much from those estimated from the fixed-effects model.

A negative shock to human capital notably decreases the rate of output growth in non-OECD countries in all the estimation methodologies we report in tables 2-4. For the OECD group, the effect of exogenous shocks remains inconclusive; though we find a significant negative estimated coefficient for the physical capital shock variable in the two-step system GMM (Table 4 Column 5).[20]

5.3 Robustness

We estimate several other variants of the benchmark model to verify the robustness of the results from the fixed-effects model and the GMM. Tables 5 and 6 display estimations using fixed-effects model for OECD and non-OECD countries, respectively, while tables 7 and 8 show from two-step difference and two-step system GMM estimation for non-OECD countries.

[20] Reliability of these results remains a concern since for the small sample size of the OECD subgroup results may suffer bias from over-fitting the endogenous variable because the number of instrument is large relative to the number of cross-sectional units in the panel.

We add institutional control variables (political risk and democracy measures); adopt Sachs and Warner's (1997) suggestion to test for non-linear impact of human capital; and investigate whether there is a lagged effect of exogenous shocks. We find that none of the estimated coefficients for exogenous shocks seem to be much affected by altering the model specifications. We still fail to find any significant evidence on the relationship between per capita output growth rates and exogenous shocks in the OECD countries. In contrast, in the non-OECD countries, a negative shock to human capital is significantly associated with the lower per capita output growth, while the impact of a negative shock on physical capital is muted.

6. Conclusion

All previous empirical growth research (that we are aware of) assumes that countries have reached their steady-state growth path and derives its conclusions regarding the validity of the various theories based on this assumption. In this paper, we do not examine the determinants of the level of per capita income as an indication that a certain theory has better explanatory power. Rather, we focus here on the dynamics of growth following an external shock.

Empirically describing the typical dynamic response of the economy to an exogenous shock, we argue, may lead us to doubt the validity of some growth theories and hypotheses. We find that the data analysis we present suggests that the neo-classical model does not accord very well with the growth experience of developing (non-OECD) countries. We find that a negative shock to the stock of human capital results in a decreased growth rate (with no eventual return to the previous growth trajectory) while negative shocks to the stock of physical capital do not seem to have much statistically observable effect in our dataset.

Our framework allows us to observe that certain theories do not fit the patterns we observe; however, it does not allow us to discriminate between the various theories that conform to our empirical findings. We cannot, for example, differentiate between the validity of the Romer and the Uzawa-Lucas models of endogenous growth as both models give same predictions regarding the shock to human capital. Our framework also does not allow us to differentiate between the theories that postulate multiple equilibria and in which the sorting mechanism that involves the choice of a certain equilibrium is not well specified.

Normal caveats inherent in work relying on cross-country macro-economic datasets should be acknowledged. While we see our results as robust to various estimation techniques, they are only as good as the quality of the data we rely on.

One can also use our results to shed further light on other recent hypotheses concerning long-run growth. For example, Fiaschi and Lavezzi (2007) find that a non-linear transition path to the steady state describes the growth trajectory better than the canonical theoretical models. They argue that there is a flat region for low and high income stages and a steeper take-off region at the middle of the income distribution.[21] In this case, maybe our paper is a contribution that can explain some of these described non-linearities of the growth path.

[21] Aizenman and Spiegel (2007) analyzed this middle range takeoff stage.

Table 1. Summary Statistics of Disaster Variables

Sample	Variable	Mean	St.Dev.	Min	Max	Countries	Observations
All	KILL	0.005	0.04	0	0.751	98	476
	DAMAGE	1.83	5.89	0	72.85	98	476
OECD	KILL	0.001	0.003	0	0.028	27	133
	DAMAGE	0.56	1.20	0	9.24	27	133
Non-OECD	KILL	0.008	0.05	0	0.751	71	343
	DAMAGE	2.14	6.51	0	72.85	71	343

Full definitions and sources of each variable are provided in Appendix B.

Table 2. Fixed-Effects Estimates

Sample	All	All	All	OECD	OECD	Non-OECD	Non-OECD
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Initial income	-9.64***	-9.69***	-9.61***	-12.95***	-13.25***	-8.97***	-8.83***
	(2.43)	(2.42)	(2.43)	(4.00)	(4.04)	(2.69)	(2.71)
Initial Schooling	-0.29	-0.26	-0.29	0.58	0.60	-1.03	-1.07
	(0.48)	(0.48)	(0.48)	(0.40)	(0.40)	(0.78)	(0.79)
Fertility rate	-0.07	-0.11	-0.06	0.32	0.32	-0.21	-0.14
	(0.35)	(0.36)	(0.36)	(0.62)	(0.64)	(0.50)	(0.50)
Investment	0.13***	0.13***	0.13***	0.21***	0.21***	0.10**	0.10**
	(0.04)	(0.04)	(0.04)	(0.06)	(0.06)	(0.05)	(0.05)
Government consumption	-0.03	-0.03	-0.04	-0.06	-0.06	-0.02	-0.02
	(0.03)	(0.03)	(0.03)	(0.04)	(0.04)	(0.04)	(0.04)
Openness	0.00	0.01	0.01	0.07***	0.07***	0.00	-0.00
	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.01)	(0.01)
KILL		-6.58***		-39.40		-6.51**	
		(2.70)		(26.74)		(2.78)	
DAMAGE			0.01		-0.08		0.01
			(0.02)		(0.09)		(0.03)
Adjusted R-squared	0.28	0.28	0.28	0.56	0.56	0.27	0.26
Observations	476	476	476	133	133	343	343
Hausman	18.69**	18.88*	22.09***	16.06	18.05*	19.15**	24.06***

Notes: The dependent variable is the growth rate of per capita real GDP. Regressions include time-effect dummies that are not reported. Numbers in parentheses are heteroskedasticity-consistent standard errors. *** indicates significance at the 1% level; ** at the 5% level; * at the 10% level. The Hausman test is for the consistency of the random-effects estimator compared to the fixed-effects estimator. The significance of the test statistic indicates that the fixed-effect estimation is appropriate.

Table 3. Two-Step Difference GMM Estimates

Sample	All (1)	All (2)	All (3)	OECD (4)	OECD (5)	Non-OECD (6)	Non-OECD (7)
Initial income	-18.50*	-25.71*	-19.82	-23.55***	-21.91***	-33.89***	-24.21**
	(10.11)	(13.78)	(12.31)	(6.01)	(5.55)	(12.51)	(10.65)
Initial Schooling	-1.47	-1.28	0.21	2.21***	1.69***	2.36	1.39
	(2.02)	(2.20)	(1.62)	(0.66)	(0.51)	(2.76)	(2.64)
Fertility rate	-1.78**	-1.78**	-1.01	1.17	0.41	-0.54	-0.54
	(0.87)	(0.79)	(0.83)	(1.15)	(1.00)	(1.16)	(1.15)
Investment	0.14	0.09	0.15	0.29***	0.23*	0.00	0.06
	(0.11)	(0.11)	(0.11)	(0.11)	(0.13)	(0.16)	(0.14)
Government consumption	-0.04	-0.07	-0.05	-0.08*	-0.06	-0.05	0.01
	(0.06)	(0.08)	(0.06)	(0.05)	(0.06)	(0.12)	(0.08)
Openness	0.10**	0.13***	0.07	0.06*	0.06*	0.08*	0.06
	(0.04)	(0.04)	(0.05)	(0.03)	(0.03)	(0.04)	(0.04)
KILL		-5.50		-80.52		-5.68*	
		(3.53)		(87.66)		(3.31)	
DAMAGE			0.04		-0.21		0.04
			(0.04)		(0.14)		(0.04)
Observations	378	378	378	106	106	272	272
Number of Countries	95	95	95	27	27	68	68
F-test	7.35***	7.18***	8.46***	11.01***	14.63***	4.70***	6.24***
Arellano-Bond test (p-value)	0.65	0.83	0.90	0.68	0.55	0.45	0.58
Hansen test (p-value)	0.96	0.90	0.93	0.63	0.79	0.74	0.95

Notes: The dependent variable is the growth rate of per capita real GDP. Regressions include time-effect dummies that are not reported. Numbers in parentheses are the Windmeijer finite-sample corrected heteroskedasticity-consistent standard errors. *** indicates significance at the 1% level; ** at the 5% level; * at the 10% level. The significance of F-test statistics indicates the overall fit of the regressions. The Arellano-Bond test is the test for AR(2) in first differences under the null hypothesis of no serial correlation. The Hansen test is the test for joint validity of the instruments. The null hypothesis is that the instruments used all are not correlated with the residuals.

Table 4. Two-Step System GMM Estimates

Sample	All	All	All	OECD	OECD	Non-OECD	Non-OECD
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Initial income	-0.80	0.61	0.51	-10.59**	-9.52**	1.24	0.70
	(3.21)	(3.44)	(3.67)	(5.01)	(4.24)	(4.77)	(3.71)
Initial Schooling	-0.81	-0.87	-0.84	1.34**	1.19*	-0.59	0.05
	(0.53)	(0.58)	(0.54)	(0.66)	(0.65)	(1.44)	(1.11)
Fertility rate	-0.78*	-0.55	-0.53	0.42	0.02	-0.64	-0.31
	(0.42)	(0.41)	(0.46)	(0.85)	(0.82)	(0.68)	(0.66)
Investment	0.20***	0.19**	0.19***	0.24*	0.24*	0.27***	0.30***
	(0.08)	(0.08)	(0.08)	(0.14)	(0.13)	(0.09)	(0.07)
Government consumption	-0.06	-0.06	-0.06	-0.03	-0.02	-0.05	-0.00
	(0.04)	(0.05)	(0.04)	(0.03)	(0.03)	(0.07)	(0.04)
Openness	0.01	0.00	0.00	0.03**	0.03**	-0.02	-0.01
	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)
KILL		-8.11**		13.43		-6.86*	
		(3.83)		(50.20)		(4.19)	
DAMAGE			0.01		-0.17**		-0.01
			(0.03)		(0.09)		(0.04)
Observations	476	476	476	133	133	343	343
Number of Countries	98	98	98	27	27	71	71
F-test	9.02***	6.86***	7.83***	17.88***	49.69***	6.41***	4.59***
Arellano-Bond test (p-value)	0.83	0.95	0.86	0.45	0.38	0.91	0.97
Hansen test (p-value)	0.77	0.60	0.78	0.99	0.996	0.12	0.23

Notes: The dependent variable is the growth rate of per capita real GDP. Regressions include time-effect dummies that are not reported. Numbers in parentheses are the Windmeijer finite-sample corrected heteroskedasticity-consistent standard errors. *** indicates significance at the 1% level; ** at the 5% level; * at the 10% level. The significance of F-test statistics indicates the overall fit of the regressions. The Arellano-Bond test is the test for AR(2) in first differences under the null hypothesis of no serial correlation. The Hansen test is the test for joint validity of the instruments. The null hypothesis is that the instruments used all are not correlated with the residuals.

Table 5. Fixed-Effects Estimates: Robustness Test for OECD Countries

	(1)	(2)	(3)	(4)	(5)	(6)
Initial income	-13.69***	-13.85***	-12.82***	-13.12***	-12.98***	-13.27***
	(3.90)	(3.93)	(4.05)	(4.09)	(4.10)	(4.13)
Initial Schooling	0.53	0.54	0.59	0.62	0.51	0.56
	(0.40)	(0.41)	(0.41)	(0.41)	(1.21)	(1.23)
Fertility rate	0.68	0.68	0.23	0.24	0.29	0.31
	(0.57)	(0.58)	(0.63)	(0.66)	(0.75)	(0.71)
Investment	0.19***	0.19***	0.21***	0.21***	0.21***	0.21***
	(0.07)	(0.07)	(0.06)	(0.06)	(0.06)	(0.07)
Government consumption	-0.07**	-0.07**	-0.05	-0.05	-0.06	-0.06
	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)	(0.04)
Openness	0.05**	0.05**	0.07**	0.07***	0.07***	0.07***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Political risk Index	0.09**	0.10**				
	(0.04)	(0.04)				
Democracy Index			-0.03	-0.03		
			(0.09)	(0.09)		
Initial schooling squared					0.01	0.00
					(0.12)	(0.13)
KILL	-16.81		-39.84		-39.31	
	(25.86)		(27.75)		(26.99)	
DAMAGE		-0.04		-0.07		-0.07
		(0.08)		(0.09)		(0.09)
Adjusted R-squared	0.60	0.60	0.56	0.56	0.56	0.56
Observations	133	133	133	133	133	133
Hausman	20.25**	20.67**	16.42	62.65***	16.14	17.45

	(7)	(8)
Initial income	-12.80***	-13.21***
	(4.16)	(4.26)
Initial Schooling	0.57	0.60
	(0.41)	(0.41)
Fertility rate	0.32	0.32
	(0.62)	(0.64)
Investment	0.21***	0.21***
	(0.06)	(0.07)
Government consumption	-0.06	-0.06
	(0.04)	(0.04)
Openness	0.07***	0.07***
	(0.02)	(0.02)
KILL	-36.91	
	(29.26)	
DAMAGE		-0.07
		(0.09)
KILL (-1)	17.65	
	(45.85)	
DAMAGE (-1)		0.01
		(0.13)
Adjusted R-squared	0.56	0.56
Observations	133	133
Hausman	15.56	15.29

Notes: The dependent variable is the growth rate of per capita real GDP. Regressions include time-effect dummies that are not reported. Numbers in parentheses are heteroskedasticity-consistent standard errors. *** indicates significance at the 1% level; ** at the 5% level; * at the 10% level. The Hausman test is for the consistency of the random-effects estimator compared to the fixed-effects estimator. The significance of the test statistic indicates that the fixed-effect estimation is appropriate.

Table 6. Fixed-Effects Estimates: Robustness Test for Non-OECD Countries

	(1)	(2)	(3)	(4)	(5)	(6)
Initial income	-6.97**	-6.75**	-8.05***	-7.84***	-9.08***	-8.95***
	(3.08)	(3.08)	(3.17)	(3.18)	(2.68)	(2.69)
Initial Schooling	-1.42	-1.47*	-0.55	-0.59	-1.88	-1.99
	(0.89)	(0.89)	(0.91)	(0.91)	(1.34)	(1.35)
Fertility rate	0.06	0.14	0.05	0.13	-0.22	-0.15
	(0.52)	(0.53)	(0.54)	(0.55)	(0.50)	(0.50)
Investment	0.09*	0.09	0.06	0.06	0.11**	0.11**
	(0.06)	(0.06)	(0.05)	(0.05)	(0.05)	(0.05)
Government consumption	-0.00	-0.01	-0.03	-0.03	-0.02	-0.03
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Openness	-0.00	-0.01	0.00	0.00	-0.00	-0.00
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Political risk Index	0.11***	0.12***				
	(0.03)	(0.03)				
Democracy Index			0.08	0.08		
			(0.07)	(0.07)		
Initial schooling squared					0.23	0.25
					(0.28)	(0.28)
KILL	-5.74*		-6.15**		-6.42**	
	(3.43)		(2.90)		(2.75)	
DAMAGE		0.01		0.01		0.01
		(0.03)		(0.02)		(0.02)
Adjusted R-squared	0.30	0.30	0.26	0.25	0.26	0.26
Observations	295	295	328	328	343	343
Hausman	20.99***	26.41***	17.36	21.32**	19.86***	24.44***

	(7)	(8)
Initial income	-8.92**	-9.22***
	(2.76)	(2.78)
Initial Schooling	-1.03	-1.01
	(0.78)	(0.79)
Fertility rate	-0.21	-0.13
	(0.51)	(0.50)
Investment	0.10**	0.11**
	(0.05)	(0.05)
Government consumption	-0.02	-0.02
	(0.04)	(0.04)
Openness	0.00	-0.00
	(0.01)	(0.01)
KILL	-6.65***	
	(2.76)	
DAMAGE		0.02
		(0.03)
KILL (-1)	-0.26	
	(2.20)	
DAMAGE (-1)		0.03
		(0.02)
Adjusted R-squared	0.26	0.26
Observations	343	343
Hausman	17.18	24.42***

Notes: The dependent variable is the growth rate of per capita real GDP. Regressions include time-effect dummies that are not reported. Numbers in parentheses are heteroskedasticity-consistent standard errors. *** indicates significance at the 1% level; ** at the 5% level; * at the 10% level. The Hausman test is for the consistency of the random-effects estimator compared to the fixed-effects estimator. The significance of the test statistic indicates that the fixed-effect estimation is appropriate.

Table 7. Two-Step Difference GMM Estimates: Robustness Test for Non-OECD countries

	(1)	(2)	(3)	(4)	(5)	(6)
Initial income	-33.26***	-25.34***	-20.83***	-13.72	-30.83***	-26.96***
	(7.18)	(10.27)	(9.98)	(10.59)	(10.44)	(10.07)
Initial Schooling	0.80	2.38	-2.87	-2.08	-0.45	0.41
	(2.63)	(2.93)	(4.36)	(4.58)	(3.95)	(3.67)
Fertility rate	-0.31	0.75	-2.08	-1.44	-0.85	-0.40
	(1.21)	(1.02)	(1.64)	(1.51)	(0.98)	(0.88)
Investment	-0.07	0.01	0.25*	0.22*	0.06	0.09
	(0.16)	(0.14)	(0.14)	(0.11)	(0.15)	(0.11)
Government consumption	-0.02	-0.01	0.05	0.05	-0.00	0.05
	(0.09)	(0.11)	(0.09)	(0.08)	(0.10)	(0.07)
Openness	0.09***	0.05*	0.09***	0.06*	0.06	0.06
	(0.03)	(0.03)	(0.03)	(0.03)	(0.05)	(0.04)
Political risk Index	0.09	0.09				
	(0.09)	(0.06)				
Democracy Index			0.08	0.07		
			(0.14)	(0.11)		
Initial schooling squared					0.79	0.66
					(0.72)	(0.67)
KILL	-5.94		-7.18*		-6.09*	
	(3.73)		(3.76)		(3.69)	
DAMAGE		0.06		0.05		0.02
		(0.06)		(0.05)		(0.04)
Observations	236	236	260	260	272	272
Number of Countries	59	59	65	65	68	68
F-test	4.54***	4.38***	5.92***	6.43***	5.34***	5.91***
Arellano-Bond test (p-value)	0.35	0.19	0.81	0.81	0.42	0.41
Hansen test (p-value)	0.57	0.74	0.58	0.86	0.74	0.95

Notes: The dependent variable is the growth rate of per capita real GDP. Regressions include time-effect dummies that are not reported. Numbers in parentheses are the Windmeijer finite-sample corrected heteroskedasticity-consistent standard errors. *** indicates significance at the 1% level; ** at the 5% level; * at the 10% level. The significance of F-test statistics indicates the overall fit of the regressions. The Arellano-Bond test is the test for AR(2) in first differences under the null hypothesis of no serial correlation. The Hansen test is the test for joint validity of the instruments. The null hypothesis is that the instruments used all are not correlated with the residuals.

Table 8. Two-Step System GMM Estimates: Robustness Test for Non-OECD countries

	(1)	(2)	(3)	(4)	(5)	(6)
Initial income	-3.59	-2.01	-0.35	-0.82	-0.09	0.24
	(4.78)	(4.52)	(4.08)	(3.19)	(4.14)	(3.19)
Initial Schooling	0.34	-0.19	-0.95	-0.39	-1.00	-0.36
	(1.25)	(1.06)	(1.36)	(1.20)	(1.85)	(1.58)
Fertility rate	-0.58	-0.59	-0.76	-0.63	-0.84	-0.59
	(0.95)	(1.03)	(0.69)	(0.70)	(0.75)	(0.69)
Investment	0.36***	0.35***	0.32***	0.33***	0.29***	0.29***
	(0.09)	(0.07)	(0.07)	(0.07)	(0.09)	(0.08)
Government consumption	-0.12**	-0.11**	-0.03	-0.02	-0.03	0.00
	(0.06)	(0.05)	(0.06)	(0.05)	(0.06)	(0.04)
Openness	-0.03*	-0.03***	-0.01	-0.01	-0.02	-0.01
	(0.02)	(0.01)	(0.03)	(0.02)	(0.02)	(0.02)
Political risk Index	0.02	0.05				
	(0.06)	(0.08)				
Democracy Index			0.02	-0.04		
			(0.11)	(0.12)		
Initial schooling squared					0.09	-0.00
					(0.39)	(0.39)
KILL	-6.41*		-8.53**		-7.44**	
	(3.86)		(3.78)		(3.85)	
DAMAGE		-0.03		-0.03		-0.01
		(0.04)		(0.03)		(0.04)
Observations	295	295	328	328	343	343
Number of Countries	59	59	68	68	71	71
F-test	5.52***	7.64***	5.19***	4.83***	7.20***	4.89***
Arellano-Bond test (p-value)	0.12	0.21	0.89	0.98	0.93	0.89
Hansen test (p-value)	0.18	0.24	0.26	0.38	0.27	0.38

Notes: The dependent variable is the growth rate of per capita real GDP. Regressions include time-effect dummies that are not reported. Numbers in parentheses are the Windmeijer finite-sample corrected heteroskedasticity-consistent standard errors. *** indicates significance at the 1% level; ** at the 5% level; * at the 10% level. The significance of F-test statistics indicates the overall fit of the regressions. The Arellano-Bond test is the test for AR(2) in first differences under the null hypothesis of no serial correlation. The Hansen test is the test for joint validity of the instruments. The null hypothesis is that the instruments used all are not correlated with the residuals.

Appendix A: List of Countries

Algeria	Greece	Pakistan
Argentina	Guatemala	Panama
Australia	Guinea-Bissau	Papua New Guinea
Austria	Guyana	Paraguay
Bangladesh	Haiti	Peru
Barbados	Honduras	Philippines
Belgium	Hungary	Poland
Benin	Iceland	Portugal
Bolivia	India	Rwanda
Botswana	Indonesia	Senegal
Brazil	Iran	Sierra Leone
Burundi	Ireland	Singapore
Cameroon	Israel	South Africa
Canada	Italy	Spain
Central African Republic	Jamaica	Sri Lanka
Chile	Japan	Sweden
China	Jordan	Switzerland
Hong Kong	Kenya	Syria
Colombia	Korea	Tanzania
Congo	Lesotho	Thailand
Costa Rica	Malawi	Togo
Cyprus	Malaysia	Trinidad &Tobago
Denmark	Mali	Tunisia
Dominican Republic	Mauritania	Turkey
Ecuador	Mauritius	Uganda
Egypt	Mexico	United Kingdom
El Salvador	Mozambique	United States
Fiji	Nepal	Uruguay
Finland	Netherlands	Venezuela
France	New Zealand	Yemen
Gambia	Nicaragua	Zambia
Germany	Niger	Zimbabwe
Ghana	Norway	

Appendix B: Definitions and Sources of Variables

Variable	Definition	Source
KILL	Number of people killed by disaster as a percentage of population (5-year summation)	EM-DAT[1] and PWT[2]
DAMAGE	Damage from disaster as a percentage of GDP (5-year summation)	EM-DAT and WDI[3]
Per capita GDP growth	Growth rate of Real GDP per capita, constant prices: chain series (5-year average)	PWT
Initial income	Logarithm of real GDP per capita (at the beginning of each 5-year period)	PWT
Initial schooling	Years of secondary and higher schooling in the male population aged 15 and over (at the beginning of each 5-year period)	BL[4]
Fertility rate	Fertility rate (5-year average)	WDI
Investment	Ratio of investment to real GDP (5-year average)	PWT
Government Consumption	Ratio of government consumption to real GDP (5-year average)	PWT
Openness	Openness in constant prices (5-year average)	PWT
Political risk index	Political risk rating (5-year average)	ICRG[5]
Democracy Index	Institutionalized Democracy Index (5-year average)	POLITY4[6]

Notes:

1. EM-DAT: Database collected by the Center for Research on the Epidemiology of Disasters (CRED)
2. PWT: Penn-World Tables version 6.1
3. WDI: World Development Indicators 2006 CD-ROM
4. BL: Barro R. and J.W. Lee (2000), “International Data on Educational Attainment: Updates and Implications,” manuscript, Harvard University, February 2000.
5. ICRG: International Country Risk Guides
6. POLITY4: POLITY IV PROJECT: Political Regime Characteristics and transitions, 1800-1999 by Monty G. Marshall and Keith Jaggers.

Appendix C: An Example of Solow-Swan Model Augmented with Human Capital

Consider a particular neo-classical production function, the familiar Cobb-Douglas function that uses physical capital (K), human capital (H), and labor (L):

$$Y = AK^{\alpha} H^{\eta} L^{1-\alpha-\eta} \tag{1}$$

Rewrite equation (1) in per capita form (divide both sides by *L*), we get

$$y = Ak^{\alpha} h^{\eta} = f(k, h) \tag{2}$$

Given the exogenous saving rate *s*, the population growth rate *n*, and the capital depreciation rate δ, the accumulation of capital is given by

$$\dot{k} + \dot{h} = sAk^{\alpha} h^{\eta} - (\delta + n) \cdot (k + h) \tag{3}$$

The optimal allocation between physical and human capital is determined by the equality of their marginal products, $f_k'(k,h) = f_h'(k,h)$, which implies

$$h = \frac{\eta}{\alpha} k \tag{4}$$

Substitute equation (4) into equation (3), we get

$$\dot{k} = s\tilde{A}k^{\alpha+\eta} - (\delta + n) \cdot k \tag{5}$$

where $\tilde{A} \equiv A \cdot \left(\frac{\eta^{\eta} \alpha^{1-\eta}}{\eta + \alpha} \right)$ is a constant.

Substitute equation (4) into equation (2), we get

$$y = A \left(\frac{\eta}{\alpha} \right)^{\eta} k^{\alpha+\eta} \tag{6}$$

Based on equation (6), the growth rate of per capita output, $\frac{\dot{y}}{y}$, can be written by

$$\frac{\dot{y}}{y} = (\alpha + \eta) \frac{\dot{k}}{k} \tag{7}$$

Substitute $\frac{\dot{k}}{k}$ from equation (5) into equation (7), and then take the derivative of per capita output growth, $\frac{\dot{y}}{y}$, with respect to k :

$$\frac{\partial \dot{y}/y}{\partial k} = (\alpha + \eta)s\tilde{A}(\alpha + \eta - 1)k^{(\alpha + \eta - 2)} \tag{8}$$

In the Cobb-Douglas technology, $(\alpha + \eta) < 1$ thus $\frac{\partial \dot{y}/y}{\partial k} < 0$. The output growth rate rises as the stock of physical capital falls.

We can use equation (4) to rewrite the output growth rate in terms of human capital and take the derivative of $\frac{\dot{y}}{y}$, with respect to h,

$$\frac{\partial \dot{y}/y}{\partial h} = (\alpha + \eta)s\widehat{A}(\alpha + \eta - 1)h^{(\alpha + \eta - 2)}, \text{ where } \widehat{A} \equiv A \cdot \left(\frac{\alpha^{\alpha}\eta^{1-\alpha}}{\eta + \alpha} \right) \text{ is a constant} \tag{9}$$

One can easily shows that $\frac{\partial \dot{y}/y}{\partial h} < 0$ as $(\alpha + \eta) < 1$. The output growth rate rises as the stock of human capital falls.

References:

Abadie, Alberto, and Javier Gardeazabal, 2003. The Economic Costs of Conflict: A Case Study of the Basque Country. *American Economic Review*, 93(1), 112-132.

Abadie, Alberto, and Javier Gardeazabal,2005. Terrorism and the World Economy. Manuscript.

Aghion, Philippe, Diego Comin and Peter Howitt, 2006. When Does Domestic Saving Matter for Economic Growth? NBER Working Paper No. 12275.

Aizenman, J. and M. Spiegel, 2007. Takeoffs. NBER Working Paper No. 13084.

Albala-Bertrand, J. M., 1993. *Political Economy of Large Natural Disasters.* Oxford, Clarendon Press.

Arellano, M., and S. Bond, 1991. Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations. *Review of Economic Studies,* 58, 277-297.

Arellano, M., and O. Bover, 1995. Another Look at the Instrumental Variables Estimation of Error-Components Models. *Journal of Econometrics*, 68, 29-51.

Barro, R.,1991. Economic Growth in a Cross Section of Countries. *Quarterly Journal of Economics*, 106, 2, 407-443.

Barro, R. and Jong-Wha Lee, 2005. IMF programs: Who is Chosen and What Are the Effects? *Journal of Monetary Economics*, 52, 1245-1269.

Barro, R., N.G. Mankiw, and X. Sala-i-Martin, 1995. Capital Mobility in Neoclassical Models of Growth. *American Economic Review*, 85, 103-115.

Barro, R., and X. Sala-i-Martin, 2003. Economic Growth. 2nd Edition; Cambridge, Mass.; The MIT Press, 2003.

Beck, Thorsten and Ross Levine, 2004. Stock Markets, Banks, and Growth: Panel Evidence. *Journal of Banking & Finance*, 28, 423-442.

Bernanke, Ben S., Refet S. Gurkaynak, 2001. Is Growth Exogenous? Taking Mankiw, Romer and Weil Seriously. NBER Working Paper No. 8365.

Blundell, R., and S. Bond, 1998. Initial Conditions and Moment Restrictions in Dynamic Panel Data Models. *Journal of Econometrics*, 87(1), 115-143.

Cass, David, 1965. Optimum Growth in an Aggregative Model of Capital Accumulation. *Review of Economic Studies*, 32, 233-240.

Davis, Donald, and David Weinstein, 2002. Bones, Bombs, and Break Points: The Geography of Economic Activity. *American Economic Review*, 92(5), 1269-1289.

Dercon, Stefan, 2004. Growth and Shocks: Evidence from Rural Ethiopia. *Journal of Development Economics*, 74, 309– 329.

Dooley, M, D. Folkerts-Landau, and P. Garber, 2004. The US Current Account Deficit and Economic Development: Collateral for a Total Return Swap. NBER Working Paper No. 10727.

Doppelhofer, Gernot and Melvyn Weeks, 2007. Jointness of Growth Determinants. CESIFO Working Paper No. 1978.
Durlauf, Steven, Andros Kourtellos, and Chih Ming Tan, 2008. Are Any Growth Theories Robust? *Economic Journal* 118, 329–346.

Easterly, William, Michael Kremer, Lant Pritchett and Lawrence H. Summers, 1993. Good Policy or Good Luck? Country Growth Performance and Temporary Shocks. NBER Working Paper No. 4474.

Farmer, Roger E. A. and Amartya Lahiri, 2006. Economic Growth in an Interdependent World Economy. *Economic Journal*, 116, 969–990.

Fiaschi, Davide and Andrea Mario Lavezzi, 2007. Nonlinear Economic Growth: Some Theory and Cross-country Evidence. *Journal of Development Economics* 84, 271–290.

Hallegatte, Stéphane, 2006. Can Natural Disasters Have Positive Consequences? Investigating the Role of Embodied Technical Change. Manuscript, Stanford University.

Hallegatte, Stéphane, Jean-Charles Hourcade and Patrice Dumas, 2007. Why Economic Dynamics Matter in Assessing Climate Change Damages: Illustration on Extreme Events. *Ecological Economics* 62, 330-340.

Hausman, J.A., 1978. Specification Tests in Econometrics. *Econometrica* 46, 1251-1271.

Hausman, Jerry, 2001. Mismeasured Variables in Econometric Analysis: Problems from the Right and Problems from the Left. *Journal of Economic Perspectives* 15(4), 57–67.

Horwich, George, 2000. Economic Lessons of the Kobe Earthquake. *Economic Development and Cultural Change* 521-542.

Howitt, Peter, 2000. Endogenous Growth and Cross-Country Income Differences. *American Economic Review*, 90(4), 829-846.

Islam, N., 1995. Growth Empirics: A Panel Data Approach. *Quarterly Journal of Economics* 110, 1127-1170.

Jones, C., 1995. Time Series Tests of Endogenous Growth Models. *Quarterly Journal of Economics*, 110, 495–525.

Koopmans, Tjalling C., 1965. On the Concept of Optimum Economic Growth. In *the Econometric Approach to Development Planning*, Amsterdam: North Holland.

Levine, Ross E. and Renelt, David, 1992. A Sensitivity Analysis of Cross-Country Growth Regressions. *American Economic Review*, *82*(4), 942–963.

Lucas, Robert E., Jr., 1988. On the Mechanics of Economic Development. *Journal of Monetary Economics*, 22, 3-42.

Mankiw, N. G., D. Romer, and D. Weil , 1992, A Contribution to the Empirics of Economic Growth. *Quarterly Journal of Economics*, 107(2), 407-437.

McQuinn, Kieran and Karl Whelan, 2007a. Solow (1956) as a model of cross-country growth dynamics. *Oxford Review of Economic Policy* 23, 45–62.

McQuinn, Kieran and Karl Whelan, 2007b. Conditional convergence and the dynamics of the capital-output ratio. *Journal of Economic Growth* 12, 159–184.

Miguel, Edward and Gerard Roland, 2006. The Long Run Impact of Bombing Vietnam. NBER Working Paper No. 11954.

Minier, Jenny, 2007. Nonlinearities and Robustness in Growth Regressions. *American Economic Review* 97(2), 388-392.

Noy, Ilan, 2008. The Macroeconomic Consequences of Disasters. *Journal of Development Economics*, forthcoming.

Popper, Karl, 1959. *The Logic of Scientific Discovery*. New York: Basic Books.

Raddatz, Claudio, 2007. Are External Shocks Responsible for the Instability of Output in Low-income Countries? *Journal of Development Economics* 84 (1), 155–187.

Ramcharan, Rodney, 2007. Does the Exchange Rate Regime Matter for Real Shocks? Evidence from Windstorms and Earthquakes. *Journal of International Economics* 73(1), 31–47.

Ramsey, Frank, 1928. A Mathematical Theory of Saving. *Economic Journal*, 38, 543-559.

Romer, Paul M., 1986. Increasing Returns and Long-run Growth. *Journal of Political Economy* 94(5), 1002-1037.

Romer, Paul M., 1990. Endogenous Technological Change. *Journal of Political Economy*, 98(5), 71-102.

Roodman, David, 2006. How to Do xtabond2: An Introduction to “Difference” and “System” GMM in Stata. Working Papers 103, Center for Global Development.

Sachs, J. and A. Warner, 1997. Fundamental Sources of Long-run Growth. *American Economic Review*, 87(2), 184-188.

Sala-i-Martin X., 1997. I Just Ran Two Million Regressions. *American Economic Review*, 87(2), 178-183.

Sala-i-Martin X., Doppelhofer G, and Miller RI, 2004. Determinants of Long-Term Growth: A Bayesian Averaging of Classical Estimates (BACE) Approach. *American Economic Review* 94(4), 813-835.

Schumpeter, Joseph A., 1934. The Theory of Economic Development. Cambridge, Mass: Harvard University Press.

Skidmore, Mark and Hideki Toya, 2002. Do Natural Disasters Promote Long-run Growth? *Economic Inquiry* 40(4), 664-687.

Solow, Robert M., 1956. A Contribution to the Theory of Economic Growth. *The Quarterly Journal of Economics*, 70 (1), 65-94.

Swan, Trevor W., 1956. Economic Growth and Capital Accumulation. *Economic Record*, 32, 334-361.

Uzawa, H., 1965. Optimal Technical Change in an Aggregate Model of Economic Growth. *International Economic Review*, 6, 18-31.

Yang, Dean, 2006. Coping With Disaster: The Impact of Hurricanes on International Financial Flows. NBER Working Paper No. 12794.