

What do Exogenous Shocks Tell Us about Growth Theories?

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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.

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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 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. Broadly, and crudely, these can be grouped into two categories: the AK models, and models that 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.

The empirical research into the sources of growth and into the three-headed debate between the neo-classical, the AK, 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 appeared later in response to skepticism about the early

¹ Romer (1986) is considered the seminal contribution in the first strand while Romer (1990) and Aghion and Howitt (1992) are seminal contributions for the second, endogenous technology literature.

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 belong 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. (2007) 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. Howitt (2000) constructs an endogenous growth model that

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.

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.³

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 the 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 thus find that the data we present, subject to the caveats we detail in the last section, suggests that the neo-classical models generally do

³ 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).

not accord very well with the growth experience of developing countries. Our framework, however, does not allow us to differentiate between, for example, the validity of the endogenous growth work, and other models that may emphasize multiple equilibria.

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 with caveats and avenues for future research.

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. The negative exogenous shocks we use in our empirical examination are natural disasters. The assumption of exogeneity of natural disasters is both intuitive, empirically supported (Noy, 2007) and in line with previous work on natural disasters (see Raddatz, 2007, Ramcharan, 2007, Skidmore and Toya, 2002, and Yang, 2006).

The impact of natural disasters on growth, on the other hand, is not at all obvious. Neo-classical frameworks predict that the destruction of physical and human capital that is usually the outcome of natural disasters will enhance growth since it will drive countries away from their balanced-growth steady states. In such cases, the loss will lead to more rapid capital (physical or human) accumulation and thus to higher temporary growth until the economy reverts back or reaches its steady state.

Models that describe the progress of technological adoption (in the Schumpeterian tradition) may also ascribe higher growth as a result of negative shocks (Hallegatte,

2006). These shocks can, for example, be catalysts for re-investment and upgrading of capital goods (like transportation and communication networks). Furthermore, disasters might be catalysts for adoption of new technologies that may be beneficial in generating (especially long-term) growth. In some sense, disasters accelerate the creative-destruction process and thus contribute to the growth this process generates. On the other hand, under some plausible assumptions, models of endogenous technological change may also yield a negative long-term impact on output growth. In particular, Hallegatte et al. (2007) note that large events may cause large GDP losses if the intensity and frequency of disasters are beyond a threshold value.

Models that have increasing returns to scale production may also predict that a destruction of part of the physical or human capital stock result in a lower growth path and consequently a permanent deviation from the previous growth trajectory. Most AK models, that have a constant growth path that is dependent on discount rates and on technology, also suggest that an economy that experiences a destruction of the capital stock will never go back to its old growth trajectory (though the growth rate will not change).

Thus, while most versions of the Solow-Swan or Ramsey models will predict increasing growth following a negative shock, an AK model will predict no change in the growth rate while endogenous technology models (e.g., the Schumpeterian models) will suggest at least a temporary decline in growth rate of output.

Using a household panel dataset, for example, 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

One other possibility, of course, is that the disasters we observe will have no impact on economic growth. This may be the case if the amount of capital that is destroyed is negligible relative to the amount of capital available for production. Horwich (2000) supports this view and notes that, from a macroeconomic perspective, 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.⁴ In a different context, Davis and Weinstein (2002) and 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.⁵

⁴ Abadie and Gardeazabal (2005) counter this argument by their finding that even a small event can cause a large shift in capital flows when international portfolios are re-balanced.

⁵ Both Davis and Weinstein. (2002) and Miguel and Roland (2006) use cross sectional estimation by country/province, and only examine the very long term impact of the US bombings several decades later.

3. Data

We follow of Islam (1995) and other studies on long-run growth by using panel data in which the entire sample period is divided into several shorter time intervals.⁶ 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 generate two different measures of exogenous shocks—human capital shocks and physical capital shocks. Human capital, by definition, refers to the stock of productive skills and technical knowledge embodied in human labor. Our measure assumes a positive relationship between an adverse effect on human capital stock and loss of life due to natural disasters. 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 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

⁶ Recent examples are Beck and Levine (2004), and Barro and Lee (2005).

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.⁷ These disasters can be hydro-meteorological, geophysical, or biological.⁸

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.⁹

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

⁷ The number of people killed includes "persons confirmed as dead and persons missing and presumed dead"; people affected are those "requiring immediate assistance during a period of emergency, i.e. requiring basic survival needs such as food, water, shelter, sanitation and immediate medical assistance.

⁸ 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).

⁹ 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 correlated with future likeliness of disaster occurrence; which is beyond our scope of interest here.

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 often 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 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 individual effects and hence give more reliable estimates.

3.1 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:

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

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.

3.2 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:

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

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:

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

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

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 following moment restrictions:

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

and

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

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. In the case that x_{it} is predetermined but not strictly exogenous, the lagged value date $t-1$ is also valid, and if it happens to be strictly exogenous, then all the x_{it} are valid instruments. Moreover, 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. The standard error of the two-step difference GMM estimator is robust as the first-step residuals are used to construct a consistent estimate of the variance-covariance matrix. 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 ‘two-step 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 (8) which imply the validity of lagged first differences as instruments for equations in levels. 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.

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

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

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.¹⁰ Of all the explanatory variables, we find that initial income and investment ratios are very significant i.e. lower initial income and higher investment as a share of real GDP are associated with an increase in long-run per capita output growth.¹¹

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 devastation of human and physical capital as a result of natural disasters will push the level of capital per capita further away from its steady-state balanced growth path, which in turn accelerates the rate of growth of capital and output per capita along its transitional path. We, however, find no statistical evidence supporting this

¹⁰ The disaster variable in Skidmore and Toya (2002) is the frequency of disasters a country experiences; we employ different measures of natural disasters.

¹¹ The negative coefficient for initial income is very robust to all specifications and estimation techniques. This appears to support the 'convergence' hypothesis.

paradigm. 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 output growth per capita significantly.

The last four columns in Table 2 report the same specifications for two subsamples: 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 on human capital, but for the OECD group neither shock variable is significant. 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 magnitude disaster data. 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

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 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 in human capital notably decreases the rate of output growth per capita in developing 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).¹²

5.3 Robustness

We conduct a number of experiments to verify the robustness of the results from the fixed-effects model and the GMM. Table 5 and Table 6 display robustness experiments using fixed-effects model for OECD and non-OECD countries, respectively. Table 7 and Table 8 show robustness experiments from two-step difference and two-step system GMM estimation for non-OECD countries.

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.

¹² Reliability of these results remains a concern since for the small sample size of the OECD subgroup results may suffer bias from overfitting the endogenous variable because the number of instrument is large relative to the number of cross-sectional units in the panel.

We also 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 developing countries, a negative shock on human capital is significantly associated with the lower per capita output growth, while the impact of a negative shock on physical capital is muted.

Endogenous growth theory seems to be more compatible with our findings. Romer (1990) emphasis on ‘research & development’ activities as a major force behind economic growth appears to be especially relevant. In this view, the stock of human capital is considered a crucial factor determining rate of economic growth since human capital is an important input in the production of new knowledge. This key aspect of endogenous growth has an obvious implication for the analysis of natural disasters. When natural disasters happen to be a serious threat to human life as well as human capital, the expected rate of return on human capital decreases which will lead to a lower investment in human capital and lower long-run growth.

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 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 on long-run growth 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 postulate multiple equilibria and in which the sorting mechanism that involves the choice of a certain equilibrium is not well specified. We cannot, for example, differentiate between the validity of much of the endogenous growth work, and some theories of growth that emphasize institutional constraints that may be affected by these shocks.

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.¹³ In

¹³ Aizenman and Spiegel (2007) analyzed this middle range takeoff stage.

this case, maybe our paper is a contribution that can explain some of these described non-linearities of the growth path.

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*** (2.43)	-9.69*** (2.42)	-9.61*** (2.43)	-12.95*** (4.00)	-13.25*** (4.04)	-8.97*** (2.69)	-8.83*** (2.71)
Initial Schooling	-0.29 (0.48)	-0.26 (0.48)	-0.29 (0.48)	0.58 (0.40)	0.60 (0.40)	-1.03 (0.78)	-1.07 (0.79)
Fertility rate	-0.07 (0.35)	-0.11 (0.36)	-0.06 (0.36)	0.32 (0.62)	0.32 (0.64)	-0.21 (0.50)	-0.14 (0.50)
Investment	0.13*** (0.04)	0.13*** (0.04)	0.13*** (0.04)	0.21*** (0.06)	0.21*** (0.06)	0.10** (0.05)	0.10** (0.05)
Government consumption	-0.03 (0.03)	-0.03 (0.03)	-0.04 (0.03)	-0.06 (0.04)	-0.06 (0.04)	-0.02 (0.04)	-0.02 (0.04)
Openness	0.00 (0.01)	0.01 (0.01)	0.01 (0.01)	0.07*** (0.02)	0.07*** (0.02)	0.00 (0.01)	-0.00 (0.01)
KILL		-6.58*** (2.70)		-39.40 (26.74)		-6.51** (2.78)	
DAMAGE			0.01 (0.02)		-0.08 (0.09)		0.01 (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	All	All	OECD	OECD	Non-OECD	Non-OECD
	(1)	(2)	(3)	(4)	(5)	(6)	(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 (3.21)	0.61 (3.44)	0.51 (3.67)	-10.59** (5.01)	-9.52** (4.24)	1.24 (4.77)	0.70 (3.71)
Initial Schooling	-0.81 (0.53)	-0.87 (0.58)	-0.84 (0.54)	1.34** (0.66)	1.19* (0.65)	-0.59 (1.44)	0.05 (1.11)
Fertility rate	-0.78* (0.42)	-0.55 (0.41)	-0.53 (0.46)	0.42 (0.85)	0.02 (0.82)	-0.64 (0.68)	-0.31 (0.66)
Investment	0.20*** (0.08)	0.19** (0.08)	0.19*** (0.08)	0.24* (0.14)	0.24* (0.13)	0.27*** (0.09)	0.30*** (0.07)
Government consumption	-0.06 (0.04)	-0.06 (0.05)	-0.06 (0.04)	-0.03 (0.03)	-0.02 (0.03)	-0.05 (0.07)	-0.00 (0.04)
Openness	0.01 (0.02)	0.00 (0.02)	0.00 (0.02)	0.03** (0.01)	0.03** (0.01)	-0.02 (0.02)	-0.01 (0.02)
KILL		-8.11** (3.83)		13.43 (50.20)		-6.86* (4.19)	
DAMAGE			0.01 (0.03)		-0.17** (0.09)		-0.01 (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*** (3.90)	-13.85*** (3.93)	-12.82*** (4.05)	-13.12*** (4.09)	-12.98*** (4.10)	-13.27*** (4.13)
Initial Schooling	0.53 (0.40)	0.54 (0.41)	0.59 (0.41)	0.62 (0.41)	0.51 (1.21)	0.56 (1.23)
Fertility rate	0.68 (0.57)	0.68 (0.58)	0.23 (0.63)	0.24 (0.66)	0.29 (0.75)	0.31 (0.71)
Investment	0.19*** (0.07)	0.19*** (0.07)	0.21*** (0.06)	0.21*** (0.06)	0.21*** (0.06)	0.21*** (0.07)
Government consumption	-0.07** (0.03)	-0.07** (0.03)	-0.05 (0.03)	-0.05 (0.03)	-0.06 (0.04)	-0.06 (0.04)
Openness	0.05** (0.02)	0.05** (0.02)	0.07** (0.02)	0.07** (0.02)	0.07** (0.02)	0.07** (0.02)
Political risk Index	0.09** (0.04)	0.10** (0.04)				
Democracy Index			-0.03 (0.09)	-0.03 (0.09)		
Initial schooling squared					0.01 (0.12)	0.00 (0.13)
KILL	-16.81 (25.86)		-39.84 (27.75)		-39.31 (26.99)	
DAMAGE		-0.04 (0.08)		-0.07 (0.09)		-0.07 (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*** (4.16)	-13.21*** (4.26)				
Initial Schooling	0.57 (0.41)	0.60 (0.41)				
Fertility rate	0.32 (0.62)	0.32 (0.64)				
Investment	0.21*** (0.06)	0.21*** (0.07)				
Government consumption	-0.06 (0.04)	-0.06 (0.04)				
Openness	0.07*** (0.02)	0.07*** (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** (3.08)	-6.75** (3.08)	-8.05*** (3.17)	-7.84*** (3.18)	-9.08*** (2.68)	-8.95*** (2.69)
Initial Schooling	-1.42 (0.89)	-1.47* (0.89)	-0.55 (0.91)	-0.59 (0.91)	-1.88 (1.34)	-1.99 (1.35)
Fertility rate	0.06 (0.52)	0.14 (0.53)	0.05 (0.54)	0.13 (0.55)	-0.22 (0.50)	-0.15 (0.50)
Investment	0.09* (0.06)	0.09 (0.06)	0.06 (0.05)	0.06 (0.05)	0.11** (0.05)	0.11** (0.05)
Government consumption	-0.00 (0.04)	-0.01 (0.04)	-0.03 (0.04)	-0.03 (0.04)	-0.02 (0.04)	-0.03 (0.04)
Openness	-0.00 (0.01)	-0.01 (0.01)	0.00 (0.01)	0.00 (0.01)	-0.00 (0.01)	-0.00 (0.01)
Political risk Index	0.11*** (0.03)	0.12*** (0.03)				
Democracy Index			0.08 (0.07)	0.08 (0.07)		
Initial schooling squared					0.23 (0.28)	0.25 (0.28)
KILL	-5.74* (3.43)		-6.15** (2.90)		-6.42** (2.75)	
DAMAGE		0.01 (0.03)		0.01 (0.02)		0.01 (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** (2.76)	-9.22*** (2.78)				
Initial Schooling	-1.03 (0.78)	-1.01 (0.79)				
Fertility rate	-0.21 (0.51)	-0.13 (0.50)				
Investment	0.10** (0.05)	0.11** (0.05)				
Government consumption	-0.02 (0.04)	-0.02 (0.04)				
Openness	0.00 (0.01)	-0.00 (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*** (7.18)	-25.34*** (10.27)	-20.83*** (9.98)	-13.72 (10.59)	-30.83*** (10.44)	-26.96*** (10.07)
Initial Schooling	0.80 (2.63)	2.38 (2.93)	-2.87 (4.36)	-2.08 (4.58)	-0.45 (3.95)	0.41 (3.67)
Fertility rate	-0.31 (1.21)	0.75 (1.02)	-2.08 (1.64)	-1.44 (1.51)	-0.85 (0.98)	-0.40 (0.88)
Investment	-0.07 (0.16)	0.01 (0.14)	0.25* (0.14)	0.22* (0.11)	0.06 (0.15)	0.09 (0.11)
Government consumption	-0.02 (0.09)	-0.01 (0.11)	0.05 (0.09)	0.05 (0.08)	-0.00 (0.10)	0.05 (0.07)
Openness	0.09*** (0.03)	0.05* (0.03)	0.09*** (0.03)	0.06* (0.03)	0.06 (0.05)	0.06 (0.04)
Political risk Index	0.09 (0.09)	0.09 (0.06)				
Democracy Index			0.08 (0.14)	0.07 (0.11)		
Initial schooling squared					0.79 (0.72)	0.66 (0.67)
KILL	-5.94 (3.73)		-7.18* (3.76)		-6.09* (3.69)	
DAMAGE		0.06 (0.06)		0.05 (0.05)		0.02 (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 (4.78)	-2.01 (4.52)	-0.35 (4.08)	-0.82 (3.19)	-0.09 (4.14)	0.24 (3.19)
Initial Schooling	0.34 (1.25)	-0.19 (1.06)	-0.95 (1.36)	-0.39 (1.20)	-1.00 (1.85)	-0.36 (1.58)
Fertility rate	-0.58 (0.95)	-0.59 (1.03)	-0.76 (0.69)	-0.63 (0.70)	-0.84 (0.75)	-0.59 (0.69)
Investment	0.36*** (0.09)	0.35*** (0.07)	0.32*** (0.07)	0.33*** (0.07)	0.29*** (0.09)	0.29*** (0.08)
Government consumption	-0.12** (0.06)	-0.11** (0.05)	-0.03 (0.06)	-0.02 (0.05)	-0.03 (0.06)	0.00 (0.04)
Openness	-0.03* (0.02)	-0.03*** (0.01)	-0.01 (0.03)	-0.01 (0.02)	-0.02 (0.02)	-0.01 (0.02)
Political risk Index	0.02 (0.06)	0.05 (0.08)				
Democracy Index			0.02 (0.11)	-0.04 (0.12)		
Initial schooling squared					0.09 (0.39)	-0.00 (0.39)
KILL	-6.41* (3.86)		-8.53** (3.78)		-7.44** (3.85)	
DAMAGE		-0.03 (0.04)		-0.03 (0.03)		-0.01 (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
Initial schooling squared	Squared value of 'Initial schooling'	
KILL (-1)	One-period lagged 'KILL'	
DAMAGE (-1)	One-period lagged 'DAMAGE'	

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.

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