ABSTRACT

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People in developing countries are more often affected by rare events, such as natural disasters and epidemics, than people in developed nations. Furthermore, the intensity of these events is usually higher in poor countries. Among policymakers, these rare events and other external shocks, such as terms-of-trade fluctuations and changes in international conditions, are often explicitly or implicitly blamed for the bad performance of growth. Do these rare events affect economic growth? Are the frequency and intensity of these rare events helpful in explaining the gap in income between rich and poor countries? The answer to this question is important not only for evaluating policies aimed at preventing these events and mitigating their consequences, but also for understanding the reasons why some countries are rich and some poor.

Although there has been a steady increase in the number of researchers tackling these questions, the effects of rare events on economic development and long-run growth remain unclear. There are some studies reporting negative effects while others report no effect or even positive effects. The purpose of this dissertation is to show that these seemingly contradictory findings can be reconciled by exploring the effects of disasters on growth separately by type of disaster. This study examines the long- term economic impact of natural disasters and epidemics and shows that different types of rare events (natural disasters and epidemics) appear to be associated with different patterns of economic vulnerability and so entail different options for reducing risk.

A few main conclusions emerge. Rare events significantly affect economic development but not always negatively, and differently across types of disasters and economic sectors. Hence, in order to understand and assess the economic consequences of natural disasters and epidemics and the implications for policy, it is necessary to consider the pathways through which different types of events affect economic development, the different risks posed, and the ways in which economies can respond to these threats.

THE MACROECONOMICS OF RARE EVENTS.

By

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Dissertation submitted to the Faculty of the Graduate School of the
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of the requirements for the degree of
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Dedication

A vos, el mayor acierto de mi vida, y a nuestro querido Achi.

A ustedes viejos, a quienes les debo todo.

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Chapter 1: Introduction

People in developing countries are more often affected by rare events, such as natural disasters and epidemics, than people in developed nations.[1] Furthermore, the intensity of these events (i.e. the number of people affected) is usually higher in poor countries.[2] Among policymakers these rare events and other external shocks, such as terms-of-trade fluctuations and changes in international conditions, are often explicitly or implicitly blamed for the bad performance of growth.[3] Are natural disasters and epidemics bad for economic growth? The answer to this question is important not only for evaluating policies aimed at preventing these events and mitigating their consequences, but also for understanding the reasons why some countries are rich and some poor.

This question may become even more relevant in the years to come if, as some observers suggest, natural disasters and epidemics continue to grow in frequency and intensity as a consequence of climate change.[4] The damages from disasters have been increasing exponentially over the last several decades (Millennium Ecosystem

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[1] For example, Benson and Clay (2004) report that the largest concentration of high-risk countries which are increasingly vulnerable to climatic hazards is in Sub-Saharan Africa.

[2] Cavallo and Noy (2010) report that "The overwhelming majority of people affected and killed by natural disasters are coming from developing countries, particularly in the Asia - Pacific region"

[3] Reports by the IMF (2003), World Bank (2004) and Unctad (2002) state that "*exogenous shocks . . . can have a significant negative impact on developing countries' growth, macroeconomic stability, debt sustainability and poverty*", and that "*low-income countries are particularly vulnerable to natural disasters, terms-of-trade shocks, and other adverse shocks*."

[4] The reader might be surprised by the assertion that "climate change" is increasing the frequency of epidemics, but this is indeed the case. Miguel A. Luque argues that "climate change is affecting the dynamic and resurgence of infectious sickness in a key fashion, concretely malaria and cholera." His study finds that a 1 degree increase in temperature generates a 5.2% increase in cholera cases. http://www.sciencedaily.com/releases/2009/04/090423133742.htm

Assessment, 2005). They are increasing in frequency and magnitude, measured both in terms of human lives lost and destroyed infrastructure (Costanza and Farley, 2007). For example, Munich Re (1999) reports that the global cost of natural disasters has increased by 1500% since 1950. In 1995 the Kobe earthquake in Japan generated about US$178 billion in losses, the equivalent of 0.7 percent of global gross domestic product.

The relevance of these rare events for the economy has instigated an incipient literature on their economic implications. However, most of the attention has concentrated on the immediate and short-run economic implications of these events, and less attention has been paid to the problems they could pose for longer-term economic growth and development. In particular, a large number of studies on the economic impacts of natural disasters have concentrated on the most easily measured direct losses, and in particular for the case of earthquakes, on the economic costs of visible physical damage. The main reason why most studies have concentrated on the short-term implications of rare events is the importance policy makers assign to measuring the needs of affected people in the aftermath of a natural disaster or epidemic. But another explanation is the practical difficulty of measuring the indirect and long-run impacts that result as the effects of a disaster shock spread through the economy.

These limitations have severely restricted the information available to policymakers, and have contributed to a failure to address the possibly serious threat that these rare events pose to sustainable development. In order to help policymakers gauge the benefits from disaster risk mitigation and adaptation, it is important both to analyze the immediate and short-run consequences or these rare events, and to have a better understanding of the long-run economic costs associated with them. The goal of this dissertation is to contribute to our comprehension of how the intensity and frequency of natural disasters and epidemics affect economic growth and development.

How can rare events affect economic growth?

Although disasters and epidemics can and sometimes do have severe negative short-run impacts, they also, can have negative longer term consequences for economic growth and development, especially when they occur frequently. As Benson and Clay (2004) argue, rare events have the potential to affect economic growth through their effect on output, investment, fiscal balances and the balance of payments.

There are several channels through which the events considered in this study can affect medium to long-run growth. For example, after a natural disaster governments may divert resources away from planned investments to fund relief and rehabilitation, or may increase external borrowing, which increases future debt-servicing payments. Additionally, by killing off mainly young adults, some epidemics may seriously shrink the tax base and thus reduce the resources available for public expenditure, including those aimed at infrastructure or development programs, or increase the budget deficit and the need for borrowing. In this regard, Cochrane (1994) explored the impact of disasters on a country's indebtedness, and concluded that disasters can lower a country's credit rating, which in turn increases interest rates on external borrowing dampening investment and reducing sustainable development. Also, frequent disasters and epidemics can contribute to economic instability and uncertainty, which may deter investment and reduce long-run growth. Finally, some epidemics may affect the accumulation of human capital and as a result reduce long-run growth.

On the other hand, some events may have a positive impact on growth. For example, large reconstruction programs required in the aftermath of an earthquake may creat a construction boom that can last several years. Furthermore, it is widely believed that the international community responds to disasters by increasing assistance. External Aid typically provides support for development, including investment in infrastructure, which has the potential to foster future growth.

In addition, disasters and epidemics could have a positive impact on medium-term growth, by instigating changes in policy that may speed up reconstruction efforts and much needed reforms. Benson and Clay (2004) argue that "*disasters can induce policy changes and institutional innovations that are ultimately beneficial, not only in reducing vulnerability but also in supporting economic growth and development*." Clay (1985) and Ahmed, Chowdhury, and Haggblade (2000) provide concrete examples. For instance, Bangladesh adopted food policy reforms directed at preventing a recurrence of the 1974 floods and containing the financial costs of subsequent floods, while the deregulation of agricultural investment after the floods in 1987 and 1988 encouraged the rapid expansion of disaster-reducing irrigation.

In summary, catastrophic events, whether natural disasters or epidemics, can induce conscious responses, relating to technical progress, policy changes, and institutional innovations, that may ultimately increase an economy's resilience and promote development.

What is the contribution of this thesis?

A good number of scholars have attempted to answer the question of whether rare events have a significant impact on the process of development. As expected, several papers report a negative effect of disasters on growth. For instance, using a cross-country sample for the period 1970-2005 (and the same database used in this thesis), Raddatz (2007) finds that rare events, including natural disasters and epidemics, lead to a reduction of real GDP growth. However, many other studies find no effect, or at times even a positive one (see Chapters 2 and Chapter 3 for details on the literature).

Overall, the current empirical literature remains inconclusive about the effects of rare events on growth. This should not be a surprise since, as explained above, economic growth theory suggests that different types of shocks can have diverse (even opposite) effects on growth. Some events could foster increases in Total Factor Productivity (TFP), for instance by easing the passage of difficult reforms (Benson and Clay, 2004). Disasters can also have differential impacts on growth due to their diverse influence on the supply of intermediate inputs, human and physical capital, etc.

This dissertation seeks therefore to reconcile the apparent contradictions in the current empirical literature through a more systematic recognition that different events affect economic sectors through different channels and that, as a result, their effects are likely to differ both by sector and by the type of disaster.

The first and most important distinction that needs to be made is between natural disasters and epidemics. Natural disasters such as droughts, floods, storms, and earthquakes tend to destroy physical capital and affect TFP, but have less effect on human capital. On the contrary, epidemics have no effect on physical capital, but have a huge impact on human capital. In other words, natural disasters and epidemics are events so different that their effects on growth should be treated separatly, contrary to Raddatz (2007). This is the approach taken in this disseration. Consequently, Chapter 2 analyzes the relationship between natural disasters and economic growth, while Chapter 3 considers the implications that epidemics have for long-term development.

Further disaggregation needs to be made between different types of natural disasters, and also between various epidemics. For the case of natural disasters, it should be clear that earthquakes are very different from climatologic hazards, such as droughts, floods and storms. First, earthquakes are random, stochastic events of uncertain and low probability, whereas climatological events occur more often. Earthquakes should thus be treated as a different type of shock than floods, droughts and storms. In addition, floods and droughts must be considered separately, since they are, indeed, opposite events and might entail very different effects on growth, particularly in agriculture.

When it comes to epidemics, there is also a strong need for disaggregation. As Chapter 3 will explain in more detail, some epidemics have a stronger effect than others on human capital accumulation, and therefore are more likely to have a negative impact on economic development. Hence, different epidemics should also be treated separately.

An important difference between the papers presented in this dissertation and the previous literature is that many previous works treat these events as isolated, one-off events rather than as recurring shocks with potentially cumulative impacts. That is a reasonable assumption for a low-probability event such as an earthquake, but in order to study the impact on long-term development of relatively frequent events, such as floods, droughts and cholera epidemics, it seems natural to undertake analysis over a longer period, such as five years, to measure the potentially cumulative impacts. Hence, the focus of this thesis is on medium-term economic growth. Another reason to focus on medium-term economic growth is that a five year horizon is typical for economic planning, which is crucial in the case of disaster reconstruction. The long run is not relevant for most governments faced with shocks.

In order to analyze the effect of natural disasters and epidemics on medium-term economic growth, I use pooled cross-country and time-series data covering 94 countries organized in non-overlapping five-year periods, with each country having at most 9 observations. I first estimate the effect of rare events on the growth rate of per capita GDP using ordinary least squares, controlling for unobserved country and regional-specific factors, time fixed effects and proxies for investment in human capital, financial depth, stability of monetary and fiscal policies, openness to international markets, and foreign shocks. Second, in order to addresses endogeneity problems and check the robustness of the OLS results, I use a dynamic panel GMM estimation procedure developed in Arellano and Bover (1995) and Blundell and Bond (1998). Specifically, these estimators address the econometric problems induced by country-specific effects, endogeneity, and the routine use of lagged dependent variables in growth regressions. I first take differences to eliminate country-specific effects and thereby remove omitted variable bias. Next, I instrument the right-hand-side variables (the differenced values of the original regressors) using lagged values of the original regressors (measured in levels) as instruments. This last step removes the inconsistency arising from simultaneity bias, including biases induced by the differenced lagged dependent variable. This methodology has increasingly been used in studies of growth (Levine, Loayza and Beck, 2000; Carkovic and Levine, 2005).

Furthermore, I complement the long term growth analysis by presenting a detailed short-run analysis of the aftermath of natural disasters and epidemics, tracing the yearly response of GDP growth to the onset of these events. This is a necessary step because, as the theoretical model shows, it can be the case that an event has no long-run (permanent) consequences for economic growth, but generates a significant decline in the short-run followed by a recovery. Using annual data, I estimate the short-run impact of natural disasters and epidemics on economic growth using a panel vector auto-regression model (panel VAR). Specifically, I focus on the orthogonalized impulse-response functions, which show the response of economic growth to an orthogonal shock in epidemics. Although this methodology has already been used to study the short-run implications of natural disasters, to my knowledge, this is the first time that is used to study the impact of epidemics.

Consistent with other studies, the data on natural disasters are obtained from the Emergency Disasters Database (EM-DAT) database of the Centre for Research on the Epidemiology of Disasters (CRED). The share of the population affected by a specific type of disaster over a given period of time is taken as the measure of natural disaster. This measure reflects both the *frequency* and *intensity* of disasters. The sample spans 94 developing and developed countries over the period 1961-2005.

In Chapter 2, I examine the effects of different natural disasters (droughts, floods, earthquakes and storms) separately by economic sector (agriculture, industry, and services), controlling for a series of well known growth determinants. The paper broadens the scope of the existing literature, which has so far largely concentrated on aggregate measures of disasters and/or economic activity. This disaggregated approach also yields preliminary insights into the distributive effects of natural disasters. Here, three major conclusions emerge. First, different disasters affect growth in different economic sectors differently and the results obtained with over-aggregated data are misleading. Second, while moderate disasters can have a positive growth effect on certain sectors, severe disasters do not. Third, growth is more sensitive to natural disasters in developing than developed countries—more sectors are affected, the magnitudes are larger and non-trivial, and the poor are more likely to be more affected by disasters (both positively and negatively.)

Chapter 3 performs a similar analysis but with epidemics. The main finding of Chapter 3 is that different types of epidemics have different effects on economic growth. In particular I find that Cholera epidemics increase growth in the short and long run, while Influenza epidemics produce a negative effect on short-run growth, but no effect in the long-run. Furthermore, I find that the epidemics-growth relationship is robust to using instrumental variables to control for endogeneity.

The most important prescription coming out from the present study is that risk management strategies need to recognize that diferent types of events have very different implications for the macroeconomy. The two broad categories of natural disasters and epidemics appear to be associated with different patterns of economic vulnerability and so entail different options for reducing risk. To understand and assess the economic consequences of natural disasters and epidemics and the implications for policy, it is necessary to consider the pathways through which different types of events affect economic development, the different risks posed, and the ways in which economies can respond to these threats.

Finally, I should emphasize that, although my work purports to study growth, it is perhaps better suited to explain the variation of "income levels," rather than "growth rates." From the regressions presented here, it is not clear whether disasters affect the long-run growth rate, the steady state level of income, or both. Disentangling the two is almost impossible, and this problem is not unique to this study. However, this problem is not as important as it may appear. A large effect on the steady state level of income may be as important in practical terms as a growth effect, and of just as much relevance for policy. As Robert Hall and Jones (1997) have suggested, this may be a more natural question, since we are only interested in growth rates because of their impact on levels. Hence, strictly speaking, in this dissertation I do not claim that rare events have an effect on the long-run growth rate of the economy; rather I claim that they represent an important influence on the future level of income per capita.

Chapter 2: Do All Natural Disasters have the same consequences for Economic Growth?

Introduction

Do all Natural Disasters have the same implications for the economy? Do droughts, floods, earthquakes and storms have the same impact on economic growth? The existing literature on the macroeconomic effects of natural disasters seems to believe that the answer to these questions is yes, as most existing studies treat all types of events as equal. Although some papers find that natural disasters reduce growth, others find no significant relationship or even a positive one. The thesis of the present work is that existing studies have missed a very important point: different types of disasters have diverse (even opposite) effects on growth. Therefore, if droughts, floods, earthquakes and storms are treated as if they are the same event, their estimated effect on growth will be ambiguous.

The aim of the present paper is to fill this gap in the literature by studying the disaggregated impact of disasters (i.e. droughts, floods, earthquakes and storms) on the growth rate of aggregate GDP per capita and the growth rate of per capita value added of the agriculture, industry and service sectors. The main contribution of the paper is to show that the relationship between natural disasters and growth depends on the type of disaster being considered.

The fact that the current empirical literature remains inconclusive about the effects of natural disasters on growth should not necessarily come as a surprise, as economic growth theory suggests that different types of disasters can have diverse (even opposite) effects on growth, in particular at the sectoral level. Some disasters could foster increases in Total Factor Productivity (TFP), for instance by easing the passage of difficult reforms (Benson and Clay, 2004). Disasters can also have differential impacts on growth due to their diverse influence on the supply of intermediate inputs. Consider, for instance, droughts and floods: while droughts reduce the supply of water, an essential input for agriculture, floods increase it, and under some circumstances may therefore increase agricultural production (a prediction consistent with our empirical findings). Even disasters that affect capital, such as earthquakes, need not reduce growth: Okuyama (2003) and Hallegatte and Dumas (2009), for instance, study circumstances under which destroyed capital could be replaced with more productive capital, thus fostering medium term growth. Growth theory suggests therefore that disasters can have a positive impact on growth, in particular at the sectoral level. Whether this is actually the case remains an empirical question.

This paper estimates the impact of natural disasters on economic growth directly using cross-country data disaggregated by sector and type of disaster, thereby avoiding the pitfalls of existing models and their reliance on assumptions that are often difficult to justify. In some cases I relate the findings of the paper to growth models. However, the purpose of my work is not to distinguish between specific growth models.

The analysis uses standard empirical growth equations to measure the nature and strength of statistical association between the frequency and intensity of different types of natural disasters and growth. In the first step the focus is on medium-term economic growth (five-year periods), because five year horizons are typical for to government economic planning. The effects of the different natural disasters (i.e. droughts, floods, earthquakes and storms) are examined separately by economic sector (agriculture, industry, and services), each time controlling for a series of well known growth determinants. This way the paper broadens the scope of the existing literature, which has so far largely concentrated on aggregate measures of disasters and/or economic activity. This disaggregated approach also yields preliminary insights in the distributive effects of natural disasters. Through the use of the dynamic panel GMM estimator developed by Arellano and Bover (1995) and Blundell and Bond (1998) great care is taken in addressing endogeneity issues related to the potential correlation between explanatory variables and unobserved country-specific factors.

Then, to check the robustness of the results and also to look at the path of adjustment and recovery from the different types of disasters, I run a panel-VAR using annual data to illustrate the aftermath of natural disasters. This exercise, which has been done before by Fomby et al (2010), enables me to trace the yearly response of economic growth to the four types of disasters considered.

Consistent with other studies, the data on natural disasters are obtained from the Emergency Disasters Database (EM-DAT) database of the Centre for Research on the Epidemiology of Disasters (CRED). The share of the population affected by a specific type of disaster over a given period of time is taken as the measure of natural disaster. This measure reflects both the frequency and intensity of disasters. The sample spans 94 developing and developed countries over the period 1961-2005.

I find strong evidence that different types of natural disasters have different implications for economic growth. I show that a combined index of natural disasters has a statistically insignificant effect on overall GDP growth, which reflects well the theoretical ambiguity and the inconsistent empirical evidence on the growth impact of natural disasters in the received literature. Then, I attempt to disentangle this ambiguity by disaggregating the analysis by type of disaster. I find that droughts have a negative effect on growth possibly because they entail the drastic reduction of water, a vital intermediate input in agricultural production.

Floods, on the other hand, have a positive effect on growth. They may induce a short-run disruption of agriculture and farming in the immediately affected. However, in other areas of the country and in subsequent years, the over-supply of water may lead to higher growth through an increase in land productivity due to the larger quantity of this vital intermediate input.

Earthquakes have a strong positive impact on industrial growth. Although earthquakes affect both workers and capital, they particularly destroy buildings, infrastructure, and factories. The capital-worker ratio is then sharply diminished, the average (and marginal) product of capital increases, and output grows as the economy enters a cycle of reconstruction. Moreover, if destroyed capital is replaced by a vintage of better quality, factor productivity increases, leading to further growth.

Finally, storms have a negative effect on growth. They destroy considerable amounts of physical capital, apparently more than they kill or incapacitate workers. By itself, this mechanism would suggest a growth expansion (as the capital-worker ratio drops). However, storms also have a harmful effect on communications, public utilities (including electricity), and transportation, causing severe disruption of urban life and economic activities, thus reducing productivity. The strong constraint on the supply of materials and intermediate inputs that this entails may explain why storms damage the predominantly urban economic activities of industry and services.

A few main conclusions emerge. First, different disasters affect growth in different economic sectors differently and the results obtained with over-aggregated data are misleading. Second, while moderate disasters can have a positive growth effect on certain sectors, severe disasters do not. Third, growth is more sensitive to natural disasters in developing countries than developed countries—more sectors are affected, the magnitudes are larger and non-trivial, and the poor are more likely to be affected by disasters (both positively and negatively).

Related Literature

This paper is related to papers in the growth literature and empirical studies on the macroeconomic implications of natural disasters. Empirical research on the macroeconomic implications of natural disasters has grown exponentially during the last decade. While many studies suggest a negative impact of natural disasters on immediate growth, some find no relationship, or even a positive one. Rasmussen (2004), for instance, assesses the impact of natural disasters using a cross-country sample for the period 1970 through 2002. He finds that natural disasters lead to a median reduction of 2.2% in the same-year real GDP growth, and that they increase the current account deficit and public debt. Other studies that find a negative impact are, among others, Raddatz (2007), Heger, Julca, and Paddison (2008), and Noy (2009); based on reviews of events (as opposed to cross-country studies), Charveriat (2000), Crowards (2000), and Auffret (2003) also find that major events are associated with output drops. On the other hand, an equal amount of studies find no or even a positive relationship between natural disasters and growth. Among others, Caselli and Malhotra (2004), testing the empirical validity of the predictions of the Solow model, fail to find a positive relationship between natural disasters and aggregate economic growth; and, in accordance to our findings, Jaramillo (2007) observes that the sign and magnitude of the relationship depends on the type of disaster. The paper however fails to look at sectoral growth (which we find to be equally important as the type of disaster), and does not correct for potential biases using a dynamic panel specification (see below for details). Albala-Bertrand (1993, Ch. 4) and Raddatz (2007) also find no or little effect.

A related strand of literature also demonstrates that the economic impact of disasters depends on the countries' economic and social conditions: among others, a country's level of economic development, the quality of its institutions, democratic election processes, educational attainments, and greater openness have consistently been found to reduce casualties and damages, and to improve macroeconomic performance after the event (Kahn, 2003; Rasmussen, 2004; Toya and Skidmore, 2005; Skidmore and Toya, 2007; Noy, 2009).

While the mentioned studies, including ours, analyze the relationship between natural disasters and short-run (i.e. "immediate") growth, some studies have also attempted to study how natural disasters are related to growth in the long-run. Skidmore and Toya (2002), among others, consider average per capita GDP growth over the 1960-1990, and find that climatic disasters are associated with higher long-run economic growth, while geologic disasters are negatively associated with growth; Hallegatte and Ghil (2007) find that the phase of the business cycle during which a disaster occurs affects the macroeconomic response; and Cuaresma, Hlouskova, and Obersteiner (2008) find that natural catastrophic risk is negatively associated with knowledge and technology transfers from more to less developed countries. In analyzing long-term empirical relationships, causality considerations are however complicated by biases generated by the ability of countries to adopt in the long run technologies that are less sensitive to frequent disasters.

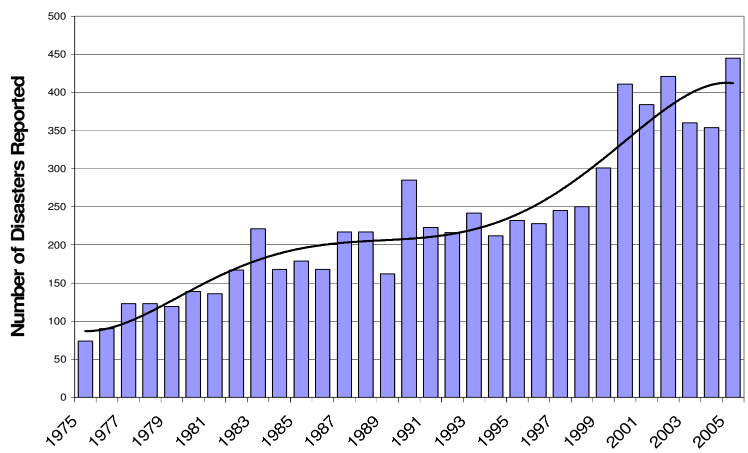
The rest of the paper is organized as follows. Section 3 presents some stylized facts on the relationship between natural disasters and economic growth; then Section 4 presents the conceptual framework to gain intuition on the implications of different types of natural disasters for economic growth. Section 5 discusses the data and empirical methodology. Finally, Section 6 presents the results of the estimation and discusses their consistency with the theoretical growth model. Section 7 concludes.

Some Stylized Facts

In thinking about natural disasters and growth, it is helpful to begin by establishing some stylized facts. This section highlights some of the most interesting regularities in the data.

I start by looking at the data on natural disasters. As defined in the EM - DAT database, natural disasters are fairly common events, and their incidence has been growing over time. Figure 1 plots the number of natural events over the span of the last four decades. The figure shows that the number of disasters has been growing over time in the world. In the Asia and Pacific region, for example, which is the region with the most events, the incidence has grown from an average of 11 events per country per decade in the 1970's to over 28 events in the 2000's. In other regions, while the increase is less dramatic, the trend is similar. However, these patterns appear to be driven to some extent by improved recording of milder events, rather than by an increase in the frequency of occurrence.

Figure 1: Trends in Natural Disasters, 1975-2005



Source: author's own calculations using data on natural disasters from CRED- EMDAT.

Contrary to Figure 1, truly large events are rare, and there is no time trend for the subset of large events in any region. For example, the frequency of large events is only 0.5 episodes per country per decaade. This suggests that there is a high incidence of small disasters in the sample or, more precisely, that the threshold for what constitutes a disaster (and hence gets recorded in the dataset) is quite lenient.

If we look at the relationship between natural disasters and growth, the most striking aspect of the data the disparity in growth rates between years with a particular disaster and years without these disasters. Table A shows the difference between the average percent growth rate in real GDP per capita and the growth rates of sectoral GDP

(Agriculture, Industry and Service) when the economy suffers natural disaster “X” and when it does not suffer disaster “X”. This provides a measure of the immediate impact of disaster “X” on the different growth rates. Table A suggests that growth in most sector of economic activity is significantly lower during years with droughts and storms, but higher during years with floods and earthquakes (although for earthquakes the difference is not statistically significant).

This feature of the data is in harmony with the results presented in Table B, which presents the outcome of regressing the different measures of growth against the different measures of natural disasters, using yearly data and controlling for country fixed effects. Table B demonstrates that, while droughts have a significant negative effect on the growth rate of GDP per capita and agricultural growth, floods have a positive one. Finally, the effects of earthquakes and storms are not.

These disparities in the growth performance across different types of natural disasters would be consistent with the view that natural disasters have diverse effects on the different sectors of the economy. This view is consistent with the empirical approach taken in this paper.

Table A

Average growth rates in years with and without Natural Disasters

Years with		**GDP Growth**	**Agricultural Growth**	**Industrial Growth**	**Service Growth**
Drought	Yes	0.1%	-3.0%	0.4%	0.8%
	No	1.7%	0.6%	2.1%	1.6%
Flood	Yes	2.2%	1.1%	1.9%	2.1%
	No	1.7%	0.2%	1.8%	1.7%
Earthquake	Yes	2.2%	1.5%	2.3%	1.9%
	No	1.5%	0.2%	1.4%	1.7%
Storm	Yes	1.6%	-0.1%	0.7%	2.2%
	No	2.1%	0.6%	2.1%	2.1%

Table B

Growth and Natural Disasters

Sample: 94 countries, 1961-2005 (Yearly Data)

Methodology: Simple OLS with country fixed effects

	Dependent Variable:			
	(1)	**(2)**	**(3)**	**(4)**
Variables	**GDP Growth**	**Agricultural Growth**	**Imdustrial Growth**	**Service Growth**
Drought	-0.0118***	-0.0311***	-0.00186	-0.00122
	(0.00319)	(0.00507)	(0.00368)	(0.00365)
Floods	0.00358**	0.00570**	0.00224	0.00418**
	(0.00175)	(0.00279)	(0.00206)	(0.00199)
Earthquakes	0.00111	0.00223	0.00195	0.00373
	(0.00415)	(0.00663)	(0.00484)	(0.00478)
Storms	-5.32e-05	-0.00200	0.000153	0.00136
	(0.00229)	(0.00333)	(0.00264)	(0.00233)
Observations	3948	3829	3749	3749
Country Fixed Effects	Yes	Yes	Yes	Yes

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Conceptual Framework

This section lays out the conceptual framework used to interpret our empirical findings in the following sections. The presentation is divided in two. First, I discuss how to think about the different implications natural disasters may have for economic development. Second, I present a simple two sector model of growth than captures a few of the most important channels through which natural disasters affect growth.

From a theoretical point of view there are various models that could rationalize how different shocks (natural disasters) affect economic growth in the medium to long-run. Some natural disasters undoubtedly have a negative short term impact on GDP, and many do affect growth negatively in the medium to long term. For example, droughts can cause heavy crop and livestock losses over wide areas, often affecting several countries simultaneously, as happened in southern Africa in the early 1990s. Extreme droughts may persist, lasting a few years. Such events have implications not only for agriculture but also for other water related, hydrologically sensitive sectors of an economy, such as hydroelectricity and domestic water supply (Hulme et al 2001).

Disasters may also affect long-run growth through increased indebtedness. Larger fiscal deficits, generated by the need to respond to natural disasters, have potential long-term development implications, primarily relating to the opportunity cost of future debt-servicing and repayment costs. Disasters can exacerbate external debt pressures to the extent that they destroy infrastructure and other assets funded with outstanding external loans. Benson and Clay (1998) show that droughts generate big fiscal inbalances. Five of the six economies analized in their paper showed a sharp increase in government borrowing in response to drought.

However, some disasters could, at least in principle, have a positive impact on medium term economic growth. While factors affecting growth negatively have been widely discussed (ranging from TFP shocks, to shocks to capital and labor, to shortages in the supply of materials/intermediate inputs), reasons why disasters can affect growth positively in the medium term (in particular at the sectoral level) have been less explored. This section reviews some of these channels.

Before doing so, observe that the empirical findings of this paper point toward a positive impact of some disasters on sectoral growth net of the initial output drop. That means that disasters create a spur to economic growth that not only allowes full recovery within the five year window we consider, but actually generate levels of per capita GDP that exceed what they would have been under the no shock scenario. Conditional convergence in exogenous growth models cannot explain such a positive impact on growth (as such models predict that levels would remain lower for several periods).

Conceptually, there are four channels through which natural disasters increase medium term growth: increases in Total Factor Productivity (TFP); increases in the supply of materials/intermediate inputs; replacement of destroyed capital with newer and more productive capital (as in a vintage capital model); and increases in capital utilization.

Natural disasters might negatively affect Total Factor Productivity in the short term by, for instance, disrupting essential transportation and communication infrastructure, lowering the productivity of capital and labor, or worsening the effectiveness of the government and other existing institutions. In the medium term, however, disasters could have a positive impact on TFP, for instance by instigating changes in policy that may speed up reconstruction efforts and much needed reforms.

A disaster affecting the supply of materials/intermediate inputs can also have vast disruptive consequences. As we shall see, however, in some rare instances disasters can have the opposite effect, and increase the supply of intermediate inputs and therefore growth in some sectors. For instance this may be the case with floods, which by increasing the supply of water may have a beneficial effect on agriculture and electricity generation.

Disasters such as earthquakes that reduce the supply of capital can also foster growth under some circumstances. Among others, this has been explored by Okuyama (2003) and Hallegatte and Dumas (2009), who study circumstances under which, in the context of a vintage capital model, replacement of old capital with more productive capital following a disaster could spur medium term growth. The likelihood of productive depends on various factors, including the severity of the shock. Hallegatte *et al* (2007) and Hallegatte and Dumas (2009), for instance, show that "poverty traps" are likely to emerge when disasters are frequent, or when reconstruction costs are considerable.

While all disasters are likely to create amix of positive and negative effects, some disasters are more likely a priori to have a negative impact on some sectors than others. Droughts and floods, for instance, through their impact on water resources, are expected to play opposite roles in agriculture: droughts should reduce agricultural production while floods may increase it. To a lesser extent, droughts and floods may also impact industrial growth by reducing (increasing) the supply of agricultural products that serve as inputs to the agro-processing industry, and by hampering (increasing) electricity generation, particularly in places where hydropower is a major source of electricity. By the same token, some earthquakes may also have a positive impact on industrial growth. Although earthquakes destroy buildings, infrastructure, and factories, in the short term, they may increase productivity in the long term to the extent that capital is replaced by a vintage of better.

A two sector model of growth

In this section I present a two sector model of growth with one consumption good. This is a relatively standard model of growth. The production technologies in the two sectors take the Cobb-Douglas form, and preferences are standard. The main purpose of the model is to provide an analytical framework to analyze the effect of different shocks on growth. Shocks differ in the sense that their direct impact bears diverse implications across the different sectors of the economy. Given the structure of the model, in order to simplify the analysis it seems reasonable to assume a closed economy.

Preferences

There is a representative household who lives infinite periods. For simplicity, I assume the size of the household is constant. The household supplies labor to the two sectors and uses its wage compensation to consume a final goods: a composite good (industrial good and services). Lifetime utility is given by:

$$\int_0^{\infty} u(c_t)e^{-\beta t}dt \,, \qquad (1)$$

where β is the subjective discount factor, c_t is a composite consumption good derived from the industrial and service sectors.

Endowments

In each period the household is endowed with one unit of time, all of which is devoted to work. Also, the household is endowed with initial capital stock at time 0 and the total land for the economy. I normalize the size of land to 1 and assume that land does not depreciate.

$$1 = n_{at} + n_{it}, \tag{2}$$

where n_{at} and n_{It} represent the amount of time that the household spends working in the agricultural sector and industrial sector respectively.

Technologies

Agriculture:

The agricultural good is produced using a Cobb-Douglas production function with labor (n_{at}) and land (L) as the only inputs.

$$x_t = A n_{at}^{\alpha} L_t^{1-\alpha} \quad , \tag{3}$$

The agricultural good is used as an intermediate input in the production of the industrial goods.

Industrial Sector:

The industrial (and service) sector produce output using standard Cobb-Douglas production functions with capital, labor and agricultural goods as inputs.

$$y_t = B k_t^{\gamma} n_{it}^{\phi} x_t^{1-\gamma-\phi}, \tag{4}$$

The industrial sector's output is used for consumption (c_t) of the composite good and to accumulate capital (invest). The law of motion of the capital stock in the economy is given by:

$$\dot{k}_t = y_t - c_t - \delta k_t, \tag{5}$$

where δ is the depreciation rate. Equation (5) is a differential equation and plays a key role in the model because it shows how the capital stock, which represents the engine of growth, changes over time.

Solution Method

There is a social planner that maximizes utility of the representative household (1), subject to constraints (2) to (5). Note that c, n_a, n_i are control variables and k, A and B are state variables of the problem. If we let λ be the co-state variable for k, we can write the current value hamiltonian as:

$$H = u(c_t) + \lambda\left[Bk_t^{\gamma} n_{it}^{\phi}\left(A(1-n_{it})^{\alpha} L_t^{1-\alpha}\right)^{1-\gamma-\phi} - c_t - \delta k\right].$$

The FOC for this problem are:

$$u'(c_t) = \lambda, \tag{6}$$

$$\phi n_{it}^{-1} = \alpha(1-\gamma-\phi)(1-n_{it})^{-1}, \tag{7}$$

$$-\dot{\lambda} + \lambda\beta = \lambda\left[\gamma Bk_t^{\gamma-1} n_{it}^{\phi}\left(A(1-n_{it})^{\alpha} L_t^{1-\alpha}\right)^{1-\gamma-\phi} - \delta\right]. \tag{8}$$

Combining the derivative of (6) with respect to time with (8) yields:

$$\dot{c}_t = -\frac{u'(c_t)}{u''(c_t)}\left[\gamma Bk_t^{\gamma-1} n_{it}^{\phi}\left(A(1-n_{it})^{\alpha} L_t^{1-\alpha}\right)^{1-\gamma-\phi} - \delta - \beta\right].$$

From (7) we get:

$$\overline{n}_i = \frac{\phi}{\phi + \alpha(1-\gamma-\phi)}.$$

The second dynamic equation is given by the law of motion of capital:

$$\dot{k}_t = Bk_t^{\gamma} n_{it}^{\phi} x_t^{1-\gamma-\phi} - c_t - \delta k_t.$$

Assuming $u(c) = \ln c$, we have a dynamic system of equations:

$$\frac{\dot{c}_t}{c_t} = \gamma B k_t^{\gamma-1} \Phi A^{1-\gamma-\phi} - \delta - \beta, \quad (9)$$

$$\dot{k}_t = Bk_t^{\gamma} \Phi A^{1-\gamma-\phi} - c_t - \delta k_t, \quad (10)$$

where $\Phi = \overline{n}_i^{\phi}[(1-\overline{n}_i)^{\alpha} L_t^{1-\alpha}]^{1-\gamma-\phi}$.

This model, which is almost identical to the one sector Ramsey model, is interesting for its predictions about the behavior of the growth rates and other variables along the transition path, from a given initial stock of capital (k_0) to its steady-state level of capital (k^{ss}), and is also very useful to analyze the dynamics that follow after shocks hitting the economy.

I now proceed to fully characterize the qualitative behavior of the dynamic system in the (k; c) plane. The phase-diagram in Figure 1, shows the nature of the dynamics of the model. Since, the rest of the variables are functions of (*k; c*) we don't need to pay attention to them. To construct the phase diagram, we first draw the: $\dot{c} = 0$ and $\dot{k} = 0$ curves. To obtain these curves, I first set $\dot{c} = 0$, which defines the first loci. We see that there are two ways for $\dot{c} = 0$: c=0, which corresponds to the horizontal axis in Figure 1, and the vertical line at the steady-state level of capital defined by:

$$k^{ss} = \left[\frac{\gamma B \Phi A^{1-\gamma-\phi}}{\delta + \beta}\right]. \quad (11)$$

Here, we should note that when $k<k^{ss}$, $c>0$, that is, when the capital stock is below its steady-state value, consumption of industrial goods is increasing. On the other hand, when $k>k^{ss}$, $c<0$, in words, when the capital stock is above its steady-state value, consumption of industrial goods is decreasing.

The second step in the construction of the phase-diagram is to find the $\dot{k}=0$ loci. It can be seen from equation (10) that $\dot{k}=0$ if:

$$c = Bk^{\gamma} n^{\phi} x^{1-\gamma-\phi} - \delta k \quad . \tag{12}$$

Note that when present capital is close to zero, the derivative of c with respect to k goes to infinity and when present capital goes to infinity, the derivative converges to a negative number. Formally:

$$\lim_{k\to 0} \frac{\partial c}{\partial k} = \infty$$
$$\lim_{k\to \infty} \frac{\partial c}{\partial k} = 0$$

The next step is to linearize this dynamic system around the steady state. The linear approximation of the dynamic system around the steady state is given by:

$$\begin{bmatrix} \dot{c} \\ \dot{k} \end{bmatrix} = \begin{bmatrix} 0 & \gamma(\gamma-1)BA^{1-\gamma-\phi}k^{\gamma-2}\Phi \\ -1 & \gamma B k_t^{\gamma-1}\Phi A^{1-\gamma-\phi} - \delta \end{bmatrix} \begin{bmatrix} c_t - c^{ss} \\ k_t - k^{ss} \end{bmatrix}.$$

The determinant of the matrix associated with the linear approximation is negative:

$$\Delta = -\gamma(\gamma-1)BA^{1-\gamma-\phi}k^{\gamma-2}\Phi < 0$$

Since the determinant is the product of the two roots, a negative determinant implies that the system has one positive and one negative root, in other words, there is only one stable arm that is upward-sloping. Given that the only predetermined variable is k, the system exhibits saddle path stability. As shown in the picture, this means that for a given value of k_0, c_0 will adjust so as to position the system along the saddle path.

Effects of Natural Disasters: An Analytical Illustration

In this sub-section I use the model to examine, analytically, the effect of different types of shocks (Natural Disasters). I start by analyzing a shock that reduces the capital stock of the economy. Since this type of shocks affect capital, it only has implications for the Industrial sector. As I will explain latter, Earthquakes belong to this group of shocks. Then I go on to study the effect of events that affect the productivity of the agricultural sector and also a combination of shocks. In later sections I'll make the argument that most Natural Disasters belong to one of these categories, and thus the following exercise provides an analytical framework to understand the empirical results.

Suppose that the economy is initially in the steady-state given by point A in Figure 2 There is then an "unanticipated" shock that reduces the capital stock of the economy. In Figure 2, I show how the economy will respond. With the help of the phase-diagram, we can find out the behavior of consumption and the capital stock. The first thing to notice is that this event does not change the steady-state. As equations (11) and (12) make clear, the steady-state values of consumption and capital do not depend on the current capital stock.

Note that on impact, the economy's capital stock falls. In terms of the phase diagram depicted in Figure 2, the capital stock jumps from kss to a point such as k0. What happens to consumption? Consumption will have to adjust, immediately after the event, so that the system lies along the saddle path. Hence, on impact, the system jumps for point A to Point B in Figure 2. The system then travels back to the unchanged steady-state (point A). The corresponding time paths of consumption and capital stock are also depicted in the diagram. Given that the capital stock is increasing, output is growing. The fall in consumption leads to an increase in investment which diminishes over time as consumption and the capital stock return to its initial level.

Other shocks that are related to this paper are the ones that affect the productivity in the agricultural sector. The two Natural Disasters that fit in this category are Droughts and Floods.

Suppose again that the economy is initially in the steady-state given by point A in Figure 3, Panel (a) and that at t = 0, there is an unanticipated event that lowers the productivity of the agricultural sector, in particular assume that there is a shock that reduces A (increases A in Panel (b)). How is the steady-state affected? From (11) and (12), it follows that both steady-state consumption and steady-state capital stock fall (increase in Panel (b)). Intuitively, since the productivity in the agricultural sector is lower (higher), output will go down and production in the non-agricultural sector will also be affected because of the decrease in intermediate inputs (the opposite direction when Panel (b)). With fewer (more) resources, the non-agricultural sector will produce a lower (higher) level of output. The new steady-state will be thus at a point like B in Figure 3. How does the economy go from point A to point B? On impact, the capital stock cannot jump. Hence, the economy must jump on impact from point A to point C to position itself along the saddle path. It then travels over time from point C towards point A. The corresponding paths of consumption and capital stock are illustrated in Figure 3, Panels (a) and (b). The consumption paths implies that the economy will disinvest (invest) over time. To get rid of the unwanted stock of capital (augment the stock of capital in the case of Panel (b)), during the transition the economy will consume an amount higher (lower) than the implied by the new steady-state and output will be growing at a positive (negative) rate.

Finally, I analyze the effect of a shock that reduces the stock of capital but also affects productivity of the industrial sector. In particular, assume that there is a shock that destroys a small amount of capital but also diminishes A, which seem to replicate the effect of Storms. This shock is a combination of the first two analyzed above. On impact, the reduction in the stock of capital moves the economy away from its initial steady-state, but by affecting productivity, the steady-state is also affected. The overall effect on growth depends on whether the current capital stock is below or above the new steady-state. As shown in Figure 4, if after the impact the capital stock is above the new steady-state level, the economy will position the system along the new saddle path, and capital will decrease on time until it reaches the new steady state. During the transition, output growth will be negative, the economy will be disinvesting.

While this section has highlighted theoretical circumstances under which, in principle, disasters can have a positive impact on growth, the extent to which they actually do so remains an empirical question that is explored in the next sections. A last theoretical point should however be raised before proceeding with the empirics. The larger the disaster, the less likely it is that it will have a positive impact on growth. This is because large disasters that annihilate much of the infrastructure and civic ability to respond make recovery a difficult process, and therefore should hamper growth in both the short and medium term. The empirical analysis will therefore distinguish between the impacts of moderate versus major disasters.

Estimation Methodology

In this section I present the empirical strategy used to identify the impact of different types of natural disasters on the growth rates of GDP per capita and sectoral GDP per capita. The point of departure is a standard growth regression equation designed for estimation using (cross-country, time-series) panel data:

$$y_{i,t} - y_{i,t-1} = \beta_0 y_{i,t-1} + \beta_1 CV_{i,t} + \beta_2 ND_{i,t} + \mu_t + \eta_i + \varepsilon_{i,t} \qquad (3.1)$$

Where the subscripts *i* and *t* represent country and time period, respectively; *y* is the log of output per capita, *CV* is a set of growth control variables, and *ND* represents natural disasters; μ_t and η_i denote unobserved time- and country-specific effects, respectively; and ε is the error term. The dependent variable ($y_{i,t}$-$y_{i,t-1}$) is the average rate of real output growth (i.e., the log difference of output per capita normalized by the length of the period).

I include controls and country and year fixed effects to control for differences between developing and OECD countries, which likely suffer different magnitudes of shocks. The controls $CV_{i,t}$, are included to capture transitory shocks (such as terms of trade shocks) that confound the correlation between output and natural disasters. For example, a country that suffered from negative terms of trade shocks might have a significantly stronger negative correlation between natural disasters and growth vis a vis a country that had positive terms of trade shocks. However, this would not necessarily mean that the relation between natural disasters and growth is different in these countries. The specific controls used will be further discussed in the next section.

The coefficient of interest is β_2, which measures the partial correlation of output and natural disasters. The challenge is to obtain a consistent and precise estimate of β_2, and examines differences between high-income and developing countries.

This task is not straightforward. We start by estimating the model using OLS including country and time dummies. However, when the model is estimated using OLS, serious problems could arise. First, reverse causality could generate biases in estimation of β_2, of given that economic growth can affect the impact and intensity of future natural disasters. In addition, estimating the dynamic panel model presented above presents an additional complication described by Nickell (1981). A methodology that deals with country specific effects, dynamic panel bias and endogeneity is the GMM estimator developed by Arellano and Bond (1991). This estimator works in the following way: After accounting for time-specific effects, equation 3.1 can be rewritten as:

$$y_{i,t} = \alpha\, y_{i,t-1} + \beta X_{i,t} + \eta_i + \varepsilon_{i,t} \qquad (3.2)$$

with $X_{i,t}$ including $CV_{i,t}$ and $ND_{i,t}$. To eliminate the country-specific effect, take first differences of equation 3.2:

$$y_{i,t} - y_{i,t-1} = \alpha\left(y_{i,t-1} - y_{i,t-2}\right) + \beta'\left(X_{i,t} - X_{i,t-1}\right) + \left(\varepsilon_{i,t} - \varepsilon_{i,t-1}\right) \qquad (3.3)$$

First differencing gets rid of the country specific effects, but leads by construction to a correlation between the differenced lagged fiscal variable and the differenced error term. Furthermore, this step does not solve the problem of reverse causality. Thus, instrumental variable estimation is called for.

Following Levine, Loayza, Beck (2000) and Dollar and Kraay (2004), the generalized method of moments (GMM) estimators developed for dynamic models of panel data introduced by Holtz-Eakin, Newey, and Rosen (1988), Arellano and Bond (1991), and Arellano and Bover (1995) are used to control for country-specific effects and joint endogeneity in this dynamic panel growth regression model. These estimators are based, first, on differencing regressions to control for (time invariant) unobserved effects and, second, on using previous observations of explanatory and lagged-dependent variables as instruments (which are called internal instruments).

The consistency of the GMM estimators depends on whether lagged values of the explanatory variables are valid instruments in the growth regression. Two specification tests are run to verify this. The first is the Hansen test of overidentifying restrictions, which tests the validity of the instruments by analyzing the sample analog of the moment conditions used in the estimation process. Failure to reject the null hypothesis gives support to the model. The second test examines whether the original error term (that is, $\varepsilon_{i,t}$ in equation (3.2)) is serially correlated. The model is supported when the null hypothesis is not rejected.[5] See the appendix for more details on the GMM methodology.

Growth Determinants and Natural Disasters

To perform the estimations, a pooled cross-country and time-series data panel is compiled covering 94 developing and developed countries over the period 1961-2005.

[5] In the system specification, it is in fact tested whether the first-differenced error term (that is, the residual of the equation in differences) is second-order serially correlated. First-order serial correlation of the differenced error term is expected even if the original error term (in levels) is uncorrelated, unless the latter follows a random walk. Second-order serial correlation of the differenced residual indicates that the original error term is serially correlated and follows a moving average process of at least order one.

The data are organized in non-overlapping five-year periods, with each country having at most 9 observations. The panel is unbalanced, with some countries having more observations than others. Appendices 1 and 2 provide summary statistics of the variables both for the pooled sample and developing countries only. Appendix 3 presents a matrix of pair-wise correlations of these variables. All data except the data on natural disasters are from World Bank's World Development Indicators (WDI, 2007).

Four dependent variables are considered. For comparison with other studies, regressions are first run using the growth rate of real per capita Gross Domestic Product (GDP) as the dependent variable. Subsequently regressions use the growth rate of real per capita value added in the three major sector of the economy, that is, agriculture, industry and services. All of them are measured as the five-year average of the log differences of per capita output (in 2000 US dollars). Per capita output is obtained by dividing the value added of each sector by the total population.

Three groups of growth determinants are considered: 1) variables that measure transitional convergence, structural and stabilization policies, and institutions; 2) variables that proxy the role of external conditions affecting growth performance; and 3) natural disasters, which form the subject matter of the paper. To control for transitional convergence, in each regression the corresponding initial value of output per capita (in logs) for the five-year period is used. This is crucial to test whether the initial position of the economy is important for its subsequent growth, all things equal. A negative sign would suggest that poor economies tend to catch up and grow faster than rich economies.

Similar to the cross-country growth specifications by Levine, Loayza, Beck (2000) and Dollar and Kraay (2004), I include controls for education, financial development, monetary and fiscal policy, and trade openness to capture the role of structural and stabilization policies, and institutions. Education is proxied by the log of the gross enrollment rate in secondary school, which is the ratio of the number of students enrolled in secondary school to the number of persons of the corresponding age. Financial depth is measured by the ratio of private domestic credit supplied by private financial institutions to GDP. The fiscal burden is measured as the ratio of general government consumption to GDP. Openness to international trade is proxied by the volume of trade (exports and imports) divided by GDP.

The consumer price index (CPI) inflation rate is a proxy for macroeconomic stabilization, with high inflation being associated with bad macroeconomic policies. Financial depth, the government consumption ratio, trade openness, and the inflation rate[6] enter the growth regressions as the log of the average for the corresponding five-year period. All these control variables are assumed to be either predetermined (independent of current disturbances, but they may be influenced by past ones) or endogenous and thus correlated with current realizations of the error term, one of the main reasons for using the GMM procedure outlined above. Specifically, regarding the difference regression corresponding to the periods t and t-1, the following instruments are used: for the variables measured as period averages--financial depth, government spending, inflation, and trade openness-- the instrument corresponds to the average of period t-2; for the variables measured as initial values--per capita output and secondary school enrollment--the instrument corresponds to the observation at the start of period t-1.

With regard to the second group of growth determinants, the regressions include two variables that are assumed to be strictly exogenous: shocks to the terms of trade and

[6] The inflation rate enters the regressions as log [100+inflation rate].

period-specific dummies. Terms of trade shocks are measured by the growth rate of terms of trade (export prices relative to import prices) over each five-year period. The idea is to capture shifts in the demand for a country's exports, and since terms of trade depend mainly on world conditions, it is assumed to be exogenous to contemporaneous growth of per capita GDP of a particular country. We include period-specific dummies to capture the impact of other global shocks to growth across countries.

Finally, data for natural disasters were obtained from the Emergency Disasters Database (EM-DAT). EM-DAT is a worldwide database on disasters maintained by CRED with the sponsorship of the United States Agency for International Development's Office of Foreign Disaster Assistance (OFDA). It contains data on the occurrence and effects of more than 17,000 disasters in the world from 1900 to the present. The database is compiled from various sources, including UN agencies, non-governmental organizations, insurance companies, research institutes and press agencies.

CRED defines a disaster as "a situation or event which overwhelms local capacity, necessitating a request to a national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering." For a disaster to be entered into the database, at least one of the following criteria must be fulfilled: 10 or more people reported killed; 100 or more people reported affected; declaration of a state of emergency; or call for international assistance.

CRED divides disasters according to type (for example: drought, flood, etc), and provides the dates when the disaster occurred and ended; the number of casualties (people confirmed dead and number missing and presumed dead); the number of people injured (suffering from physical injuries, trauma or an illness requiring immediate medical treatment as a direct result of a disaster), and the number of people affected. People affected are those requiring immediate assistance during a period of emergency (i.e. requiring basic survival assistance such as food, water, shelter, sanitation and immediate medical help). People reported injured or homeless are aggregated with those affected to produce the "total number of people affected".

Finally, EM-DAT also provides an estimate of "economic damage". Although "economic damage" could be a good indicator of the gravity of a disaster, it has important drawbacks both from a measurement and estimation perspective. First, CRED admits that there is no standard procedure to determine economic impact. Second, economic losses are reported for only one third of the disasters, with the proportion differing substantially across the types of disasters.[7] Third, such a measure would make the exogeneity assumption tenuous, as the amount of damage may be correlated with the growth during the period under consideration.

Four types of disasters will be considered: droughts, floods, storms and earthquakes. In particular, for each of these disasters the log of the sum of the total number of people affected in each event over the five -year period, divided by the total population, is taken as measure of disaster, or formally, $ND_{i,t} = Log\left(\sum_{j} \frac{Total\ Affected_{i,t,j}}{Population_{i,t}}\right)$ where j indexes the number of events that took place in country *i* during (five-year)

[7] For example, economic losses are reported for nearly 50% of all the windstorms entered in EM-DAT and 40% of the earthquakes. This is most likely due to the infrastructure damage that is directly and clearly attributable to these events. Floods are the third largest category, with losses reported for about one-third of the total events. For droughts, on the other hand, less than 25% of the events have losses reported. There may be several factors for this. In particular, CRED recognizes that droughts may only draw the international attention in terms of lives lost, with little consideration for economic costs. Droughts do not result in infrastructure or shelter damage but in heavy crop and livestock losses, therefore, most economic losses are of an indirect or secondary nature and difficult to quantify.

period *t*. By considering the sum of the number of people affected per event, the measure explicitly accounts for both the *frequency* and the *intensity* of the shock, contrary to many of the measures used in the literature. To enable comparison across countries, further normalization by the total population is undertaken to correct for differences in population size.

Inspection of the distribution of the weighted sum of natural disasters shows that it is positively skewed. Consequently the log is taken to avoid that the empirical results are driven by extreme values. Not to lose too many observations (observations for which no event has been reported result in an undefined value of the log of the disaster measure), these observations are assigned a value of to -20, which is just below the lowest observation for which an event was reported.[8] Finally, natural disasters such as storms and floods often occur in tandem—Appendix 3 indicates a correlation of 0.22 between floods and storms, and a correlation of 0.24 between floods and earthquakes. To isolate the effects of each natural disaster, the four natural disaster measures are included simultaneously in the regressions.

Empirical Results

Table 1 presents the basic estimation results using the full sample and simple OLS. The results in the first two columns pertain to the growth rate of GDP per capita, while those in the last three columns pertain to per capita value added growth rates in agriculture, industry, and services, respectively. The same set of explanatory variables is

[8] This number has been (arbitrarily) chosen to be low enough not to affect the distribution of the natural disaster indicator.

included as control variables across all regressions, except that initial output corresponds either to GDP or to the initial value-added of the respective sector.

The empirical results corresponding to the standard growth determinants (see Table 1, columns 1 and 2) are broadly consistent with the literature. Educational investment, depth of financial intermediation, and trade openness have positive and significant coefficients. Government consumption and price inflation, on the other hand, carry negative coefficients, indicating the harmful consequence of a large fiscal burden and macroeconomic price instability. More favorable terms of trade (representing external shocks) tend to improve economic growth performance.

The period dummies (not shown in the tables to save space) indicate that the international trend in economic growth experienced a declining drift over 1960-2000, resulting in a less favorable external environment in the 1980s and 1990s than in the previous decades. Perhaps surprisingly, initial output per capita is not significant. Important changes in the most recent decade regarding the roles of macroeconomic volatility and public infrastructure may explain why some of the results appear to differ from the previous literature. Most importantly, the results regarding the growth effects of natural disasters are robust to these alternative specifications of the traditional growth control variables.

Turning to the growth effects of natural disasters, natural disasters are found not to affect GDP growth when using a combined index of natural disasters—the sign of the coefficient is positive but statistically insignificant (Col. 1). The lack of a significant effect reflects well the theoretical ambiguity and the diverging empirical findings reported in the literature to date. Indeed, when disaggregating by type of natural disaster (col 2), coefficients of contrasting signs emerge (negative for droughts, earthquakes and storms, and positive for floods). However, except for floods, the coefficients fail to be statistically significant. To better understand how different disasters affect growth (and also poverty), further disaggregation of growth by economic activity is warranted.

In contrast to the weak effects on overall GDP growth, two types of natural disasters appear statistically relevant for the growth of agricultural output (Col. 3): droughts carry negative coefficients, while floods have a positive impact. On the other hand, the effects on industrial and service output growth are rather weak for the sample of all countries. In the case of industrial and service growth (Col. 4 and 5), floods are the only natural disaster that carries a significant coefficient, with a positive.

When looking at the sample of developing countries only (Table 2), the growth effects of natural disasters are stronger in significance and, in some cases, magnitude, but qualitatively the same results hold.

Now we turn our attention to Tables 3-A and 3-B. As explained earlier, the OLS regression presented above poses some challenges for estimation. Some of them were handled by using country and period specific fixed effects. However, these fixed effects do not address the problem that most of the explanatory variables are likely to be jointly determined with economic growth. So to eliminate biases resulting from simultaneity or reverse causation, I use the generalized method of moments (GMM) estimators developed for dynamic models of panel data that were introduced by Holtz-Eakin, Newey, and Rosen (1988), Arellano and Bond (1991), and Arellano and Bover (1995).

Under GMM, the statistically significant results are a subset of those under the OLS estimation. That is, there is no contradiction between the OLS and GMM results, but the latter are more precise particularly in the cases of earthquakes and storms. In particular, when we concentrate only on developing countries (Table 3-B), the results become richer and more interesting. Before focusing on developing country results in more detail, it is important to highlight that the Hansen specification and serial-correlation tests indicate that the null hypothesis of correct specification cannot be rejected, lending support to the findings. This also holds across the different follow up regressions presented in Tables 3-A to 5.

As with OLS, the coefficient on disasters is positive but insignificant when neither GDP growth nor the index of natural disasters is disaggregated by sector or type (Table 3-B, Col. 1). As before, the results gain significance and diversity once disaggregated. When the four types of natural disasters are considered individually but jointly in the regression, both droughts and floods appear to have a significant effect on per capita GDP growth, with droughts decreasing and floods raising growth (Col. 2).

The effects on agricultural growth are given in column 3. As in the full sample, droughts and floods have the largest but opposite effects. The impact of droughts is clearly negative on agricultural growth while that of floods is positive, though somewhat smaller than that for the sample as a whole. Interestingly, holding constant droughts and floods, the effect of storms is negative and significant for agricultural growth. This would imply that when the provision of water is controlled for, the plant destruction borne by storms is harm for agriculture.

Although the empirical analysis does not allow discerning the mechanisms through which the growth effects of natural disasters are realized, two channels identified by economic growth theory seem especially relevant in interpreting the contrasting effects of natural disasters on agricultural growth. The first channel through which disasters affect agricultural growth relates to the provision of raw materials and intermediate inputs: if an event decreases the availability of inputs (such as water, seedlings or unharvested plants/fruits on the fields for farming), it is likely to have a negative growth effect, and *vice versa.* The second channel is related to Total Factor Productivity and capital: if an event destroys public infrastructure (say, water dams or irrigation canals) or any other productivity determinant, its growth effect is likely to be negative.

Given the critical importance of water for agriculture, the strong negative effect of droughts on agricultural growth does not come as a surprise and is consistent with the evidence from growth studies based on micro-household data (Dercon, 2004; Christiaensen and Subbarao, 2005). Similarly, storms can have devastating effects on harvests by destroying seedlings and/or unharvested products on the field as well as irrigation infrastructure.

Viewed from this perspective, the positive effect of floods on growth comes a bit as a surprise. Too much water is clearly damaging. Yet, when floods are localized, they may be associated with plentiful supply of water nationwide, which would positively affect agriculture both directly and through the collection of irrigation water, and the net result may be a positive overall effect of floods on agricultural growth, or at worst no effect or a small negative one if floods are more widespread and severe.[9] Given the much higher frequency of reported flood events (30 percent) in the data compared to drought

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[9] Both Pooled OLS and Fixed-Effects regressions (whose results are available upon request) confirm the positive and significant association between annual rainfall (relative to the corresponding country average) and the flood intensity measure used in the paper.

events (only 8 percent, see Appendix 2B), it is indeed quite plausible that the reported floods are often moderate floods and also associated with abundant rainfall nationwide.

The impacts of disasters on the growth of industrial output are evaluated in column 4. Unlike for the full sample, droughts and floods have significant and opposite effects on industrial growth. Although the effects are analogous to the case of agriculture, their mechanisms are likely different. First, the provision of water (or lack thereof) is often a crucial input in industrial growth but for a different reason than agriculture, in that mater, in that matter often determines the electricity generating capacity of the country.

A second mechanism through which droughts and floods affect industrial growth relates to the inter-sector linkages between agriculture and industry. These (forward and backward) linkage effects are typically stronger from agriculture to non-agriculture and they are also stronger in agriculture based developing countries than in industry and service based developed economies, consistent with the observed absence of an effect of droughts and floods on industrial growth when looking at the full sample. In developing countries agricultural sectors make up a larger share of the economy and industrial production is often more dependent on agro-processing and thus inputs from agriculture (for example, cotton for textiles and grapes for wines). Similarly, robust agricultural growth fosters the demand for intermediate inputs (such as tools and fertilizer) produced by the industrial sector (so-called forward linkages). Meanwhile, backward linkages, which happen through the increased demand for (income elastic) locally produced goods and services following a widely shared increase in income, may be an even more important channel through which agricultural growth affects growth outside agriculture in developing countries (Tiffin and Irz, 2006; Haggblade, Hazell, and Dorosh, 2007). The importance of hydropower and the existence of intersectoral linkages explains why natural disasters that improve or harm agricultural growth are likely to operate in the same direction for industrial growth, at least in developing countries.

Perhaps surprisingly, both earthquakes and storms seem to lead to higher industrial growth. In terms of damage resulting from natural disasters, earthquakes and storms are distinct in that their impact on physical capital is the strongest, relative to population affected. Particularly in developing countries the damage to infrastructure inflicted by earthquakes and storms can be substantial due to lack of preparation. As discussed above, if an event produces a sharp reduction in the capital-labor ratio, it is likely to be followed by higher growth. The industrial sector stands to receive an additional growth boost from the demand for capital reconstruction that follows earthquakes and storms, from sectors including housing, infrastructure, and manufacturing.

Lastly, the effects on the growth of service output are assessed in column 5. In this case, only floods carry a significant coefficient, indicating a positive effect of floods on service value added growth. Given that this sector includes commerce and retailing, among other cross-cutting economic activities, services have strong links with both agriculture and industry, especially in developing countries, as suggested by the larger coefficient for the sample of developing countries than for the full sample. Therefore, the positive impact of floods may be partly the result of its beneficial impact on agricultural and industrial outputs.

Another mechanism through which service growth may be affected by natural disasters is that relief resources and activities may increase the demand for service-related sectors, such as transport and communications, banking, and government. This effect will tend to make the impact of all natural disasters on service value added more positive. Thus, in the case of floods, the positive effect of relief activities increases the beneficial spill-overs coming from increases in agriculture and industry. This may also be the reason why the effect of droughts on service output growth is not statistically significant: the positive relief effect counteracts the negative spill-over effect coming from agriculture and industry. Finally, unlike industry, services tend to be less intensive in physical capital, and more intensive in telecommunication and infrastructure. As a result, services are less likely to receive a growth stimulus from a decline in the capital/labor ratio, and more likely to suffer from a decline in total factor productivity following an earthquake or a storm.

Next I check the robustness of the findings, using a different measure of disasters. In particular, I use a count (incidence) variable, commonly used in the literature to measure natural disasters (e.g. IMF, 2003; Becker and Mauro, 2006), rather than the continuous (intensity) variable used in the main specification. The count variable used is the average number of events in the corresponding country and five-year window. A natural disaster qualifies as an "event" if the number of people affected times 0.3 plus the number of casualties is greater than 0.01% of the population. [10]

The results for developing countries (Table 4) are remarkably similar to those obtained with the continuous measure of natural disasters. In fact, for droughts and floods the results are the same, in terms of sign and statistical significance. For

[10] The IMF also considers disasters that cause damages of at least half a percent of national GDP.

earthquakes and storms, the count or incidence variable fails to identify a significant effect on industrial growth. As will be seen below, this reflects the fact that only moderate earthquakes and storms have a positive impact in industrial growth. Unlike the benchmark measure of disasters, the count variable does not contain enough information to discern the positive effects that result from most disasters.

Are the effects of natural disasters linear?

So far, the analysis has focused on the average effect of a disaster. Yet, the intensity of different events varies substantially, and there is no reason a priori to believe that the effects of disasters should be linear. The simple specification used so far may be a good representation of the effects of the majority of natural disasters, but it may also distort the true effects of the most severe ones. To examine this issue, the corresponding natural disaster measure is interacted with a dummy variable that has the value of 1 for the top 10% of natural disasters according to intensity, and 0 for the rest. One interaction term per natural disaster is then added to the basic regression equation, which is estimated with the same methodology as before. Results are presented in Table 5. Coefficients on interaction terms are called “Droughts Severe”, “Floods Severe”, and so on. The coefficients on the simple disaster measures (“Droughts”, “Floods”, etc.) denote the effects of moderate disasters, and the sum of the coefficients on the simple measure and the interaction term indicate the effects of severe disasters.

The results are revealing. Severe events intensify the negative effect of droughts on agricultural growth by a factor of two. In the case of floods, the positive effect estimated above seems to apply only to moderate events. In fact, the increase for aggregate GDP, agriculture, industry, and services growth disappear when floods are severe (the positive coefficient on the simple measure of floods is about the same size as the negative coefficient on the interaction term). A similar result holds for earthquakes and storms in the case of industrial growth. Both of these coefficients were significant in the basic specification. Now, the simple measures of earthquakes and storms retain those positive coefficients, but their corresponding interaction terms are negative (and significantly so in the case of storms). This implies that while moderate earthquakes and storms can have a beneficial "reconstruction" effect on industrial growth, severe events are so devastating that the best possible outcome is recovery to the sector's initial position. Overall, any potential positive effects on growth from natural disasters appear to disappear when natural disasters are extreme.

Are the effects of disasters quantitatively important?

Finally, the question remains whether the natural disasters have an important impact quantitatively, both in terms of their effects on growth and their likely effects on the distribution of that growth. To explore this, Table C presents the estimates of the annual growth effect in percentage points of a natural disaster of "typical" or median intensity, disaggregated by type of disaster and sector of economic activity. The calculations are made using the point estimates of the coefficients, presented in Table 3-B, and the median disaster intensities in the sample of developing countries, as reported in Appendix 2C.

Table C: Growth effect of a "typical" (median) natural disaster

		Effect on:			
		GDP Growth	Agricultural Growth	Industrial Growth	Service Growth
Median intensity:	Droughts	-0.606 ***	-1.071 ***	-1.029 **	-0.127
	Floods	0.996 ***	0.802 ***	0.935 ***	0.911 ***
	Earthquakes	-0.091	0.091	0.938 *	-0.071
	Storms	-0.093	-0.559 ***	0.838 *	-0.207

Note: The effects on growth are calculated using the coefficients reported in Table 2.
** significant at 10%; ** significant at 5%; *** significant at 1%*

In developing countries, a typical drought produces a reduction of agricultural and industrial annual growth rate of the order of 1 percentage point, leading to a decline of GDP growth by 0.6 percentage points per year or 3 percentage points over a period of 5 years.[11] This compares with an average annual per capita growth rate in developing countries of 1.35 percent during the 1961-2005 period. A typical flood increases growth in each major sector by about 0.8-0.9 percentage points, producing an increase of GDP growth of around 1 percentage point. A typical earthquake leads to a rise in industrial growth of about 0.9 percentage points, which, however, does not translate into an increase in aggregate growth. Finally, a typical storm has a dual effect, reducing agricultural growth by 0.6 percentage points and increasing industrial growth by 0.8 percentage points, which given the larger share of agriculture in developing economies results in a zero net effect on overall growth.

[11] Note: $y_{\text{median drought}} - y_{\text{no drought}}$ = -0.076*(-5.90 – (-20))= - 1.071

Clearly, the negative effects of droughts on aggregate and sectoral growth in developing countries can be substantial, while reports of moderate floods would in effect correspond to positive aggregate growth experiences (related to nationwide abundant rainfall). Moreover, given that the elasticity of poverty with respect to GDP is much larger for growth originating in agriculture (Christiaensen and Demery, 2007; Ligon and Sadoulet, 2007) and in labor intensive (industrial) sectors (Loayza and Raddatz, 2006), the poor stand to be especially affected by natural disasters. In particular, Christiaensen and Demery (2007) estimate that 1 percentage point of (aggregate) GDP growth originating in agriculture is on average about twice as effective in reducing 1$-day poverty than 1 percentage point of GDP growth originating outside agriculture, with an even larger difference for less developed countries. As a result, the poor are likely to suffer disproportionately from droughts and storms, with their effects often felt many years thereafter, especially in case of severe droughts as in the 1984-85 Ethiopian famine (Dercon, 2004). On the other hand, nationwide, the poor may also be benefiting disproportionately when *moderate* floods are reported. To the extent that earthquakes and storms result in labor intensive reconstruction efforts, the poorer segments of the population could benefit as well. While informative, these preliminary insights regarding the distributional effects of natural disasters must be tested further against the poverty data, an important agenda for future research.

Estimating the short-run impact of epidemics

To study the effect of natural disasters on economic growth in the short run, I use pooled cross-country and annual time-series data covering 94 countries over the period

1961-2005. The panel is unbalanced, with some countries having more observations than others.

The variables used in this section are a sub-set of the ones used in the medium and long-run analysis. The dependent variable is the growth rate of real per capita Gross Domestic Product (GDP). To capture external conditions that may affect short-run growth, I control for the growth rate of the country's Terms of Trade (TOT), to capture shifts in the demand for a country's exports. As before, data for these variables were obtained from the World Bank (WDI, 2007). The last set of variables measures the impact of droughts, floods, earthquakes and storms on the growth rates of GDP per capita, agricultural value added, and non-agricultural value added. Throughout the exercise, I assume that natural disasters are exogenous with respect to the growth variables and shocks to terms of trade.

Methodology

I study the short-run effect of natural disasters using the panel data Vector Autoregression (VAR) methodology. This technique combines the traditional VAR approach, which treats all the variables in the system as endogenous, with panel-data techniques alowing for unobserved individual heterogeneity.[12] Here I present a brief decription and the main intuition of the methodology.

I specify a first-order three-variable VAR model as follows:

$$z_{i,t} = \sum_{s=1}^{q} \Phi_s z_{i,t-s} + f_i + \varepsilon_{it}$$

[12] For a detailed discussion of the standard VAR model and the impulse-response functions see Love and Lea (2002).

where $z_t=[z_{1t}\ \ z_{2t}\ \ z_{3t}]$; z_{1t} is the number of natural disasters, z_{2t} represent terms of trade shocks and z_{3t} is the growth rate of GDP per capita, which is my main variable of interest.

I focus the analysis on the impulse-response functions, which describe the reaction of one variable in the system to the innovations in another variable in the system, holding all other shocks at zero. However, since the actual variance-covariance matrix of the errors is unlikely to be diagonal, to isolate shocks to one variabvle it is necessary to decompose the residuals in such a way that they become orthogonal. The usual convention is to adopt a particular ordering and allocate any correlation between the residuals of any two elements to the variable that comes first in the ordering. The identifying assumption is that the variables that come earlier in the ordering affect the later variables contemporaneously, as well as with a lag, while the variables that come later only affect the earlier variables with a lag. Following this convention, I assume that:

- Natural disasters have contemporaneous effects on GDP growth rates and terms of trade shocks;
- Terms of trade shocks have contemporaneous effects on GDP growth rates; but not on natural disasters;
- GDP growth shocks do not have any contemporaneous effect on the other two variables

In applying the VAR procedure to panel data, I need to impose the restriction that the underlying structure is the same for each cross-sectional unit. Since this constraint is likely to be violated in practice, one way to relax the restriction on parameters is to introduce fixed effects. Since the fixed effects are correlated with the regressors due to lags of the dependent variables, the mean differencing procedure commonly used to eliminate fixed effects will create biased coefficients. To avoid this problem I use forward mean-differencing, also referred to as the Helmert procedure (see Arellano and Bover 1995). This procedure removes only the forward mean, i.e. the mean of all the future observations available for each country-year. Since this transformation preserves the orthogonality between transformed variables and lagged regressors, we use lagged regressors as instruments and estimate the coefficients by system GMM (see Appendix for more details).

To analyze the impulse-response functions I need some estimate of their confidence intervals. Since the matrix of impulse-response functions is constructed from the estimated VAR coefficients, their standard errors need to be taken into account. Hence, I use Monte Carlo simulation to generate their confidence intervals of the impulse response functions.

Results from the Panel VAR

In this section I describe the main results of the panel VAR methodology. The presentation of the results is organized in five figures, one for an all disaster shock and then one for each type of natural disaster. For each type of shock, I present the impulse responses for its effect on real per capita GDP [panel (a)], and its major components, agricultural [panel (b)] and non-agricultural value added per capita [panel (c)]. In every figure, the pictures on the left are obtained by using the sample of all countries and the pictures on the right use the sample of developing countries only.

Before we delve into the discussion of the results, it is important to remark that they are very similar using either of the samples (all countries or developing countries). However, most of the time, the effects seem to be stronger in the sample of developing countries, therefore, I put most of the attention on the pictures of the right hand side.

As we did in the previous methodology when we looked at long-run growth, I start by looking at the effect of an "all disaster" shock on the growth rate of real GDP per capita. Once again the effect is insignificant, which reflects the theoretical ambiguities and the contradictions of the received empirical literature. Hence, we turn to the disaggregated analysis which provides richer insight.

In the previous analysis looking at five-year growth rates, we found that droughts had an overall negative effect on growth. The result of the impulse-responses presented in Figure 8 confirms this result and suggest that the initial impact is the most important. As suggested by the model presented in section 3, the effect of droughts can be explained by its direct impact in agriculture. Droughts have a strong negative impact on agriculture in the year of the event, which can not compensated by higher growth in subsequent years. This explains why we find a negative effect on the five year averages. Figure ?? also shows that through the inter-sectoral linkages presented in the model, this shock has a significant effect in non-agricultural sectors.

Contrary to droughts and as shown in the previous methodology, floods seem to have a positive effect growth that can also be explained by the direct impact on agriculture. However, the reaction of growth to a flood occurs with some delay. The response of growth of GDP and agricultural value added is positive and significant in years 1 and 2 after the event. This may indicate that in the year of the event there are two effects that may offset each other. On the one hand there is a portion of arable land (L) can not be used for production. In the model presented in section 3, this would imply a decrease in growth. On the other hand, this effect is compensated by an increase in productivity in other areas of the country that benefit from a higher supply of water. Hence, no significant effect is observed in the year of the event. However, in subsequent years when the flood is gone from areas more affected, we observe the "Nile effect", that is an increase in productivity in every area.

For earthquakes, the results are weaker in terms of statistical significance than in the case of droughts and floods. As figure 12 shows, earthquakes have no significant effect on the growth rate of GDP per capita and agricultural value added per capita. However, they seem to have a positive and significant effect for non-agricultural GDP, particularly for the sample of developing countries. This positive effect is consistent with the reconstruction activity that follows an earthquake in residential housing, public infrastructure and production plants.

Finally, the results for storms are also consistent with the long-run methodology. Storms tend to have a negative and significant effect on the growth rate of GDP per capita and non-agricultural GDP in the year of the event. For developing countries, the effects on agricultural value added per capita are contradictory. While there seems to be a negative and significant effect the year after the shock, there is a positive effect two years after the shock.

Conclusions

The literature has so far remained inconclusive regarding the effects of natural disasters on growth. While several studies point to negative effects, others report no effects or even positive effects of natural disasters on growth. Guided by insights from economic growth models on the channels through which natural disasters may affect economic growth, as well as the extensive literature on intersectoral linkages, this study went beyond the averages and explored the effects of natural disasters separately by disaster and economic sector in both developed and developing countries.

Three major insights emerged. First, disasters do affect economic growth – but not always negatively, and the effects differ substantially across disaster type and economic sector, confirming the gains from a richer disaggregated analysis that looks beyond the averages. In particular, droughts are found to have a negative impact that is mainly observed in agricultue (and also industry in developing countries). Storms also lower agricultural growth, but increase industrial growth in developing countries. Similarly, earthquakes are found to bring about higher industrial growth in developing countries. In contrast, moderate (though not severe) floods have on average a positive effect on agricultural growth, and even other sectors of the economy, likely because localized flooding reflects broader nationwide abundance of rainfall.

Second, while moderate disasters can have a positive growth effect on certain sectors, severe disasters do not. The impact of the 10 percent largest disasters in any category is found to be either insignificant or negative. When a natural disaster is severe enough, all the mechanisms that would potentially make it positive for growth are likely weakened. This also holds for severe floods and clarifies the seemingly surprising positive effect of floods. To the extent that reported floods are localized and reflective of more abundant national rainfall patterns, they would foster agriculture. Otherwise, the disruptions and damage caused by floods would cancel or outweigh the positive effects derived from plentiful rainfall.

Third, growth is more sensitive to disasters in developing than developed countries—more sectors are affected and the magnitudes are larger and non-trivial. This is consistent with the more marked presence of inter-sectoral linkages, following the more prominent role that agriculture plays in developing countries. Simulations indicate that a typical (median) drought reduces the annual per capita agricultural and industrial growth rate in developing countries by about 1 percentage point, resulting in a reduction of annual per capita overall GDP growth of 0.6 percentage points. A typical earthquake and storm increase industrial growth by about 1 percentage point each, consistent with the growth pattern predicted by theory when the capital labor ratio declines substantially, and further supported by the need for reconstruction following earthquakes and storms. As the elasticity of poverty with respect to growth generated in agriculture and labor intensive sectors (such as construction and manufacturing) is substantially higher than the elasticity of poverty with respect to growth generated in more capital intensive sectors, these results also suggest that the poor stand to be disproportionately affected.

Clearly, the time path of recovery and adjustment varies by shock and sector, and these differences will likely be further affected by country-dependent institutional factors. Our findings also suggest the presence of linkages transmitting shocks across sectors (in particular in developing countries), but cross-country regressions are not able to isolate these transmission mechanisms. While the cross-country analysis presented here provides estimates of the loss (or gain) in economic growth associated with different natural disasters, country case-studies will be needed to develop detailed policy recommendations that would ease recovery and adjustment. Such analysis would also help shed further light on the distributional impact of disasters (both in terms of geographic impact, and impact across income categories) and thus the optimal targeting of natural disaster related interventions.

Figure 3: Dynamics of the System

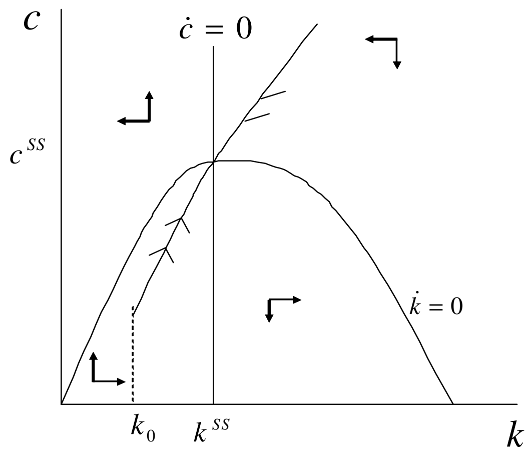


Figure 4: Effect of Droughts

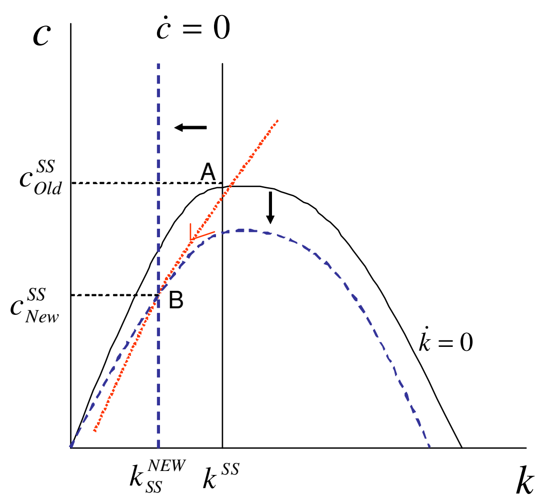


Figure 5: Effect of Floods

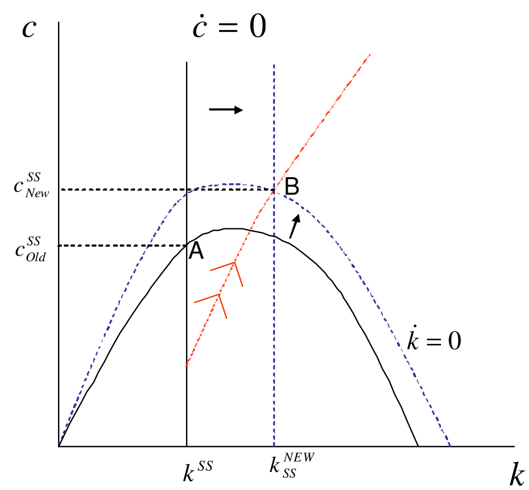


Figure 6: Effect of Earthquakes

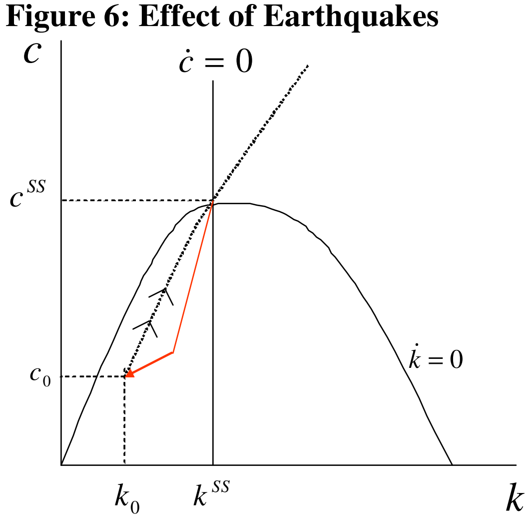


Figure 7: Effect of Storms

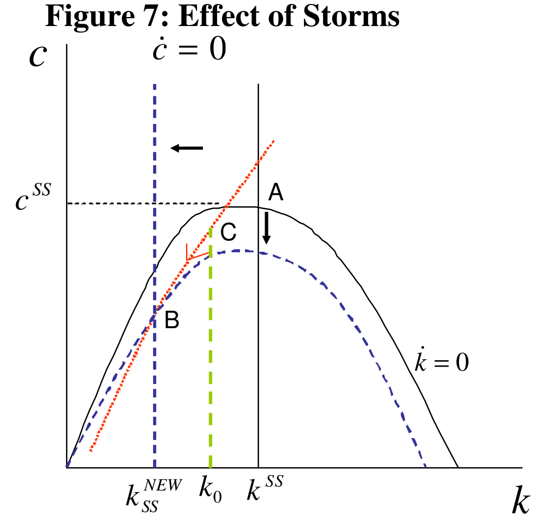


Table 1
Growth and Major Natural Disasters
Sample: 94 countries, 1961-2005 (5-year period observations)
Estimation Method: OLS Robust Regression

	Dependent Variable:				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
	GDP Growth	**GDP Growth**	**Agricultural Growth**	**Industrial Growth**	**Service Growth**
Natural Disasters Variables					
All Disasters	0.018				
intensity: log(avg. affected/population)	[0.823]				
Droughts		-0.012	-0.071***	-0.002	0.006
intensity: log(avg. affected/population)		[-0.582]	[-3.216]	[-0.0747]	[0.237]
Floods		0.069***	0.072***	0.060*	0.054**
intensity: log(avg. affected/population)		[3.389]	[2.982]	[1.779]	[2.165]
Earthquakes		-0.011	-0.007	0.002	-0.011
intensity: log(avg. affected/population)		[-0.546]	[-0.299]	[0.0497]	[-0.510]
Storms		-0.025	-0.014	-0.042	-0.022
intensity: log(avg. affected/population)		[-1.248]	[-0.610]	[-1.297]	[-0.974]
Control Variables					
Initial Output per capita	-0.202	-0.147	-0.442	-0.453**	-0.399***
	[-1.558]	[-1.059]	[-1.562]	[-2.402]	[-2.658]
Education	1.059***	1.041***	0.789***	1.108***	1.387***
	[4.932]	[4.783]	[3.081]	[2.904]	[4.843]
Financial Depth	0.563***	0.511***	-0.129	0.740**	0.765***
	[2.970]	[2.606]	[-0.627]	[2.499]	[3.292]
Government Burden	-1.447***	-1.371***	0.223	-2.023***	-1.192***
	[-4.511]	[-3.977]	[0.528]	[-3.591]	[-2.798]
Inflation	-3.657***	-3.898***	-1.436**	-5.319***	-3.493***
	[-4.654]	[-4.719]	[-2.184]	[-4.273]	[-3.834]
Trade Openness	0.418**	0.474**	-0.467*	0.929***	0.166
	[2.241]	[2.340]	[-1.696]	[2.808]	[0.678]
Growth Rate TOT	0.064***	0.064***	0.085***	0.039	0.105***
	[2.803]	[2.843]	[3.230]	[0.843]	[4.017]
Constant	18.815***	19.579***	8.690**	28.379***	18.182***
	[4.718]	[4.651]	[2.351]	[4.454]	[3.884]
Observations	544	544	544	544	544
R-squared	0.287	0.307	0.114	0.220	0.257
Number of Countries	94	94	94	94	94

t-statistics in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table 2
Growth and Major Natural Disasters Developing Countries only
Sample: 68 countries, 1961-2005 (5-year period observations)
Estimation Method: OLS Robust Regression

	Dependent Variable:				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
	GDP Growth	**GDP Growth**	**Agricultural Growth**	**Industrial Growth**	**Service Growth**
Natural Disasters Variables					
All Disasters	0.018				
intensity: log(avg. affected/population)	[0.682]				
Droughts		-0.013	-0.068***	0.001	0.002
intensity: log(avg. affected/population)		[-0.625]	[-2.909]	[0.0158]	[0.0846]
Floods		0.087***	0.081***	0.082**	0.077***
intensity: log(avg. affected/population)		[3.684]	[2.978]	[2.040]	[2.624]
Earthquakes		-0.029	0.000	-0.019	-0.027
intensity: log(avg. affected/population)		[-1.265]	[0.00523]	[-0.497]	[-1.011]
Storms		-0.027	-0.004	-0.051	-0.017
intensity: log(avg. affected/population)		[-1.216]	[-0.153]	[-1.358]	[-0.643]
Control Variables					
Initial Output per capita	-0.278	-0.217	-0.266	-0.540**	-0.530***
	[-1.645]	[-1.191]	[-0.777]	[-2.363]	[-2.661]
Education	0.919***	0.894***	0.385	0.975**	1.220***
	[4.081]	[3.860]	[1.314]	[2.250]	[3.974]
Financial Depth	0.787***	0.728***	0.136	0.961***	1.009***
	[3.480]	[3.095]	[0.609]	[2.721]	[3.540]
Government Burden	-1.457***	-1.364***	-0.090	-2.185***	-1.265**
	[-3.788]	[-3.434]	[-0.190]	[-3.381]	[-2.502]
Inflation	-3.441***	-3.574***	-0.949	-4.842***	-2.957***
	[-4.238]	[-4.277]	[-1.385]	[-3.647]	[-3.013]
Trade Openness	0.355	0.463*	-0.591*	1.007**	0.220
	[1.520]	[1.833]	[-1.860]	[2.431]	[0.703]
Growth Rate TOT	0.060**	0.061**	0.088***	0.035	0.102***
	[2.415]	[2.505]	[3.226]	[0.692]	[3.609]
Constant	17.706***	17.671***	7.190**	25.654***	15.823***
	[4.542]	[4.367]	[1.984]	[3.867]	[3.312]
Observations	407	407	407	407	407
R-squared	0.276	0.307	0.129	0.222	0.259
Number of Countries	68	68	68	68	68

t-statistics in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table 3-A
Growth and Major Natural Disasters
Sample: 94 countries, 1961-2005 (5-year period observations)
Estimation Method: System GMM

	Dependent Variable:				
	(1)	(2)	(3)	(4)	(5)
	GDP Growth	**GDP Growth**	**Agricultural Growth**	**Industrial Growth**	**Service Growth**
<u>*Natural Disasters Variables*</u>					
All Disasters	0.013				
intensity: log(avg. affected/population)	[0.602]				
Droughts		-0.016	-0.056**	0.009	0.008
intensity: log(avg. affected/population)		[-1.137]	[-2.330]	[0.467]	[0.550]
Floods		0.062***	0.090***	0.033	0.056***
intensity: log(avg. affected/population)		[3.659]	[4.392]	[1.163]	[2.881]
Earthquakes		0.003	-0.003	-0.005	-0.001
intensity: log(avg. affected/population)		[0.157]	[-0.0881]	[-0.154]	[-0.0381]
Storms		-0.002	-0.046**	-0.039	-0.011
intensity: log(avg. affected/population)		[-0.0926]	[-2.053]	[-1.127]	[-0.474]
<u>*Control Variables*</u>					
Initial Output per capita	0.102	0.147	-0.856	-0.329	-0.138
	[0.348]	[0.475]	[-1.525]	[-0.747]	[-0.465]
Education	1.292**	0.976*	2.424***	1.477	2.412***
	[2.343]	[1.698]	[4.136]	[1.451]	[5.621]
Financial Depth	0.342*	0.282	-0.383	0.393	0.252
	[1.751]	[1.447]	[-1.198]	[1.146]	[0.959]
Government Burden	-3.056***	-2.691***	-0.935	-4.182***	-3.022***
	[-5.154]	[-4.379]	[-1.468]	[-4.402]	[-3.850]
Inflation	-4.311***	-3.830***	-3.979***	-7.342***	-4.100***
	[-3.841]	[-3.480]	[-3.168]	[-3.670]	[-3.799]
Trade Openness	0.884	1.758**	1.159	1.469	1.400
	[1.412]	[2.608]	[1.349]	[1.379]	[1.640]
Growth Rate TOT	0.055***	0.053***	0.053**	0.038	0.079***
	[3.256]	[3.451]	[2.367]	[1.050]	[4.300]
Constant	21.639***	16.828**	14.919**	39.856***	17.775**
	[2.995]	[2.340]	[2.245]	[3.335]	[2.468]
Observations	544	544	544	544	544
Number of id	94	94	94	94	94
AR(1)	0.000	0.000	0.000	0.000	0.000
AR(2)	0.401	0.261	0.115	0.159	0.302
Hansen	0.744	0.801	0.789	0.574	0.155

t-statistics in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table 3-B
Growth and Major Natural Disasters - Developing Cuntries only
Sample: 68 countries, 1961-2005 (5-year period observations)
Estimation Method: System GMM

	Dependent Variable:				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
	GDP Growth	**GDP Growth**	**Agricultural Growth**	**Industrial Growth**	**Service Growth**
Natural Disasters Variables					
All Disasters	-0.002				
intensity: log(avg. affected/population)	[-0.0899]				
Droughts		-0.043***	-0.078***	-0.072**	-0.007
intensity: log(avg. affected/population)		[-2.939]	[-4.070]	[-2.213]	[-0.360]
Floods		0.076***	0.070***	0.072**	0.071***
intensity: log(avg. affected/population)		[4.665]	[4.039]	[2.612]	[4.061]
Earthquakes		-0.006	0.002	0.081*	-0.006
intensity: log(avg. affected/population)		[-0.219]	[0.0855]	[1.656]	[-0.191]
Storms		-0.012	-0.057***	0.070	-0.016
intensity: log(avg. affected/population)		[-0.460]	[-2.797]	[1.485]	[-0.540]
Control Variables					
Initial Output per capita	0.152	-0.053	0.002	-2.321**	0.014
	[0.319]	[-0.101]	[0.00247]	[-2.514]	[0.0283]
Education	0.448	0.306	1.702***	-0.218	1.782***
	[0.731]	[0.551]	[2.878]	[-0.209]	[3.030]
Financial Depth	0.679***	0.420*	-0.182	0.732*	0.458
	[2.924]	[1.785]	[-0.588]	[1.838]	[1.614]
Government Burden	-3.573***	-3.500***	-1.063*	-6.417***	-3.490***
	[-5.466]	[-5.472]	[-1.807]	[-6.339]	[-5.232]
Inflation	-6.483***	-5.850***	-3.693***	-5.293***	-3.107**
	[-5.174]	[-4.750]	[-4.806]	[-2.790]	[-2.565]
Trade Openness	1.189*	1.757**	-0.401	4.923***	2.721***
	[1.827]	[2.502]	[-0.664]	[5.017]	[3.182]
Growth Rate TOT	0.045***	0.047***	0.075***	0.055**	0.068***
	[2.771]	[3.218]	[4.017]	[2.399]	[2.895]
Constant	32.141***	29.737***	16.209***	37.912***	9.214
	[4.347]	[3.941]	[3.135]	[3.517]	[1.314]
Observations	407	407	407	407	407
Number of id	68	68	68	68	68
AR(1)	0.000	0.000	0.000	0.000	0.000
AR(2)	0.360	0.151	0.171	0.631	0.225
Hansen	0.290	0.417	0.195	0.455	0.296

t-statistics in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table 4
Incidence of Natural Disasters: Developing Countries

Sample: 68 developing countries, 1961-2005 (5-year period observations)

Estimation Method: System GMM

	Dependent Variable:				
	[1] GDP Growth	[2] GDP Growth	[3] Agricultural Growth	[4] Industrial Growth	[5] Service Growth
Natural Disaster Variables:					
All Disasters	-0.090				
avg. number of events [1]	[-0.383]				
Droughts		-2.084 ***	-2.966 ***	-2.733 ***	-0.737
avg. number of events [1]		[-4.045]	[-3.716]	[-2.587]	[-1.118]
Floods		1.048 ***	1.254 ***	1.078 **	1.627 ***
avg. number of events [1]		[3.674]	[4.025]	[2.202]	[6.235]
Earthquakes		-0.890	0.717	1.035	-1.190
avg. number of events [1]		[-1.264]	[0.745]	[0.632]	[-1.516]
Storms		-0.754 ***	-0.778 ***	-0.279	-0.819 ***
avg. number of events [1]		[-3.766]	[-4.910]	[-0.604]	[-2.839]
Control Variables:					
Initial Output per capita [2]	0.551	0.265	0.207	-1.561 *	0.110
in logs	[1.069]	[0.488]	[0.305]	[-1.807]	[0.221]
Education	0.002	0.079	1.807 **	-1.451	1.597 ***
secondary school enrollment rate, in logs	[0.004]	[0.123]	[2.483]	[-1.361]	[2.934]
Financial Depth	0.769 ***	0.641 ***	-0.389	1.131 **	0.523 **
private credit/GDP, in logs	[3.685]	[3.293]	[-1.296]	[2.397]	[2.178]
Government Burden	-3.495 ***	-3.366 ***	-0.512	-5.869 ***	-3.200 ***
government consumption/GDP, in logs	[-5.857]	[-5.355]	[-0.990]	[-5.792]	[-5.028]
Inflation	-6.308 ***	-5.626 ***	-3.553 ***	-4.833 ***	-2.692 ***
100+%Growth rate of CPI, in logs	[-5.340]	[-5.611]	[-5.669]	[-3.073]	[-3.089]
Trade Openness	1.102 *	1.138	-0.833	4.363 ***	2.171 ***
(exports+imports)/GDP, in logs	[1.695]	[1.585]	[-1.479]	[4.021]	[2.897]
Growth rate of Terms of Trade	0.048 ***	0.037 **	0.066 ***	0.043	0.066 ***
log differences of terms of trade index	[3.179]	[2.466]	[3.249]	[1.571]	[3.413]
Constant	29.693 ***	28.094 ***	16.364 ***	32.030 ***	7.771
	[4.061]	[4.214]	[3.589]	[3.213]	[1.412]
Observations	407	407	407	407	407
Number of Countries	68	68	68	68	68
Number of Instruments	47	50	50	50	50
Arellano-Bond test for AR(1) in first differences	0.000	0.000	0.000	0.000	0.000
Arellano-Bond test for AR(2) in first differences	0.371	0.144	0.167	0.758	0.391
Hansen test of overidentifying restrictions	0.328	0.388	0.497	0.485	0.314

Numbers in brackets are the corresponding t-statistics.

** significant at 10%; ** significant at 5%; *** significant at 1%*

Period fixed effects were included (coefficients not reported).

[1] An event counts as 1 if affected > 0.01% of population.

[2] Output corresponds to GDP, agricultural value added, industrial value added, and service value added, respectively.

Table 5
Severe Natural Disasters: Developing Countries
Sample: 68 developing countries, 1961-2005 (5-year period observations)
Estimation Method: System GMM

	Dependent Variable:				
	[1] GDP Growth	[2] GDP Growth	[3] Agricultural Growth	[4] Industrial Growth	[5] Service Growth
Natural Disaster Variables:					
All Disasters	0.002				
intensity: log(avg. affected/population)	[0.0931]				
All Disasters Severe	-0.043 *				
All Disasters*Top 10% drought dummy	[-1.673]				
Droughts		-0.035 **	-0.049 ***	-0.035	-0.016
intensity: log(avg. affected/population)		[-2.361]	[-2.896]	[-1.147]	[-0.797]
Droughts Severe		-0.025	-0.086 ***	-0.026	0.037
Droughts*Top 10% drought dummy		[-0.973]	[-2.793]	[-0.714]	[1.332]
Floods		0.105 ***	0.073 ***	0.100 ***	0.099 ***
intensity: log(avg. affected/population)		[5.488]	[4.252]	[3.376]	[4.581]
Floods Severe		-0.083 ***	-0.038 *	-0.091 **	-0.075 **
Floods*Top 10% flood dummy		[-3.072]	[-1.739]	[-2.222]	[-2.048]
Earthquakes		-0.028	0.005	0.081 *	-0.003
intensity: log(avg. affected/population)		[-1.139]	[0.171]	[1.685]	[-0.119]
Earthquakes Severe		0.026	-0.012	-0.058	0.005
Earthquakes*Top 10% earthquake dummy		[0.905]	[-0.427]	[-1.210]	[0.150]
Storms		-0.002	-0.062 ***	0.084 **	-0.010
intensity: log(avg. affected/population)		[-0.0625]	[-2.893]	[2.021]	[-0.280]
Storms Severe		-0.054 *	0.011	-0.143 **	-0.050
Storms*Top 10% storm dummy		[-1.662]	[0.527]	[-2.410]	[-1.370]
Control Variables:					
Initial Output per capita[1]	0.216	0.290	0.191	-1.411 *	0.195
in logs	[0.409]	[0.591]	[0.244]	[-1.883]	[0.505]
Education	0.315	0.333	1.539 **	0.134	1.607 ***
secondary school enrollment rate, in logs	[0.456]	[0.548]	[2.526]	[0.127]	[3.020]
Financial Depth	0.629 ***	0.373	-0.176	0.316	0.497 *
private credit/GDP, in logs	[2.867]	[1.488]	[-0.593]	[0.657]	[1.695]
Government Burden	-3.579 ***	-3.380 ***	-0.563	-5.922 ***	-3.514 ***
government consumption/GDP, in logs	[-5.891]	[-5.827]	[-0.981]	[-6.450]	[-5.443]
Inflation	-6.356 ***	-4.977 ***	-3.067 ***	-5.991 ***	-2.933 **
100+%Growth rate of CPI, in logs	[-5.635]	[-4.842]	[-4.270]	[-3.244]	[-2.224]
Trade Openness	1.228 **	1.832 ***	-0.520	4.486 ***	2.632 ***
(exports+imports)/GDP, in logs	[2.021]	[2.804]	[-0.962]	[4.648]	[2.792]
Growth rate of Terms of Trade	0.041 ***	0.046 ***	0.074 ***	0.025	0.065 ***
log differences of terms of trade index	[2.671]	[3.366]	[3.882]	[1.010]	[2.829]
Constant	31.305 ***	22.427 ***	13.460 ***	34.401 ***	7.343
	[4.604]	[3.510]	[2.741]	[3.203]	[0.949]
Observations	407	407	407	407	407
Number of Countries	68	68	68	68	68
Number of Instruments	48	54	54	54	54
Arellano-Bond test for AR(1) in first differences	0.000	0.000	0.000	0.000	0.001
Arellano-Bond test for AR(2) in first differences	0.332	0.247	0.204	0.663	0.229
Hansen test of overidentifying restrictions	0.394	0.669	0.322	0.444	0.311

Numbers in brackets are the corresponding t-statistics.
** significant at 10%; ** significant at 5%; *** significant at 1%*
Period fixed effects were included (coefficients not reported).
[1] Output corresponds to GDP, agricultural value added, industrial value added, and service value added, respectively.

Figure 8: Response of Growth to an All Disasters Shock

All Countries | Developing Countries

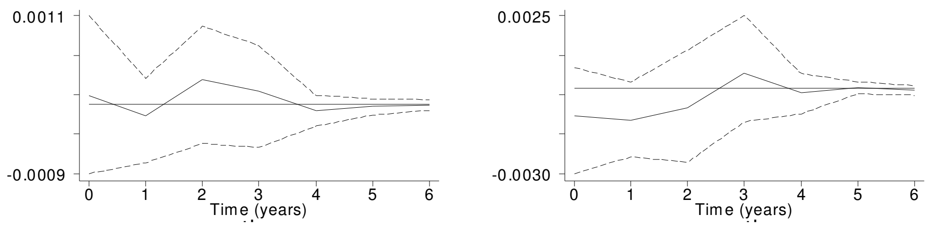
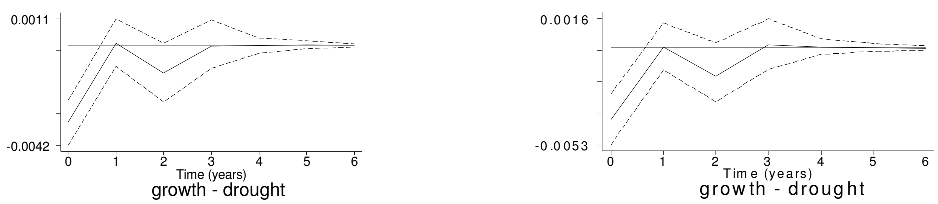


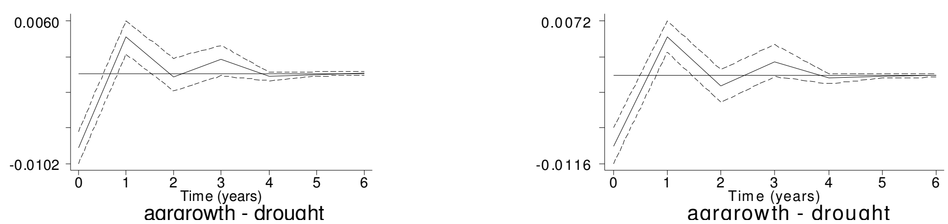
Figure 9: Effects of droughts on different measures of growth

All Countries | Developing Countries

Panel (a) - Response of Growth to Drought Shock



Panel (b) - Response of Agricultural Growth to Drought Shock



Panel (c) - Response of Non-Agricultural Growth to Drought Shock

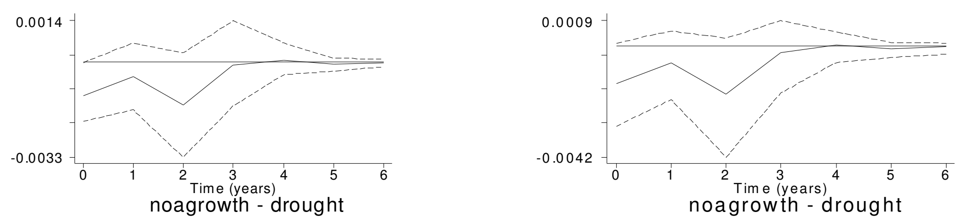
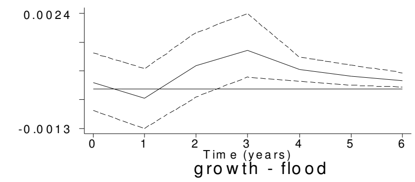
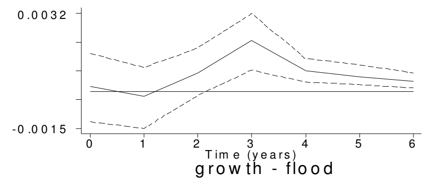


Figure 10: Effects of floods on different measures of growth

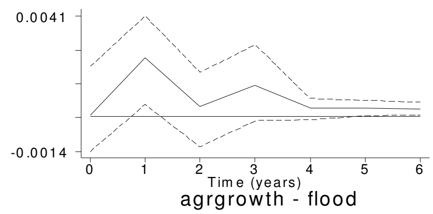
All Countries — Developing Countries

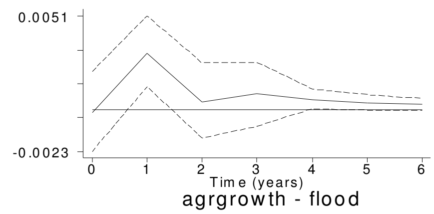
Panel (a) - Response of Growth to Floods Shock



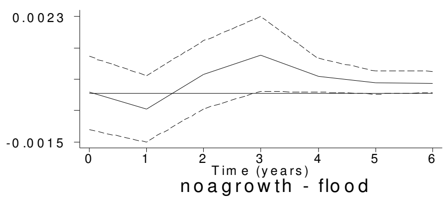


Panel (b) - Response of Agricultural Growth to Floods Shock





Panel (c) - Response of Non-Agricultural Growth to Floods Shock



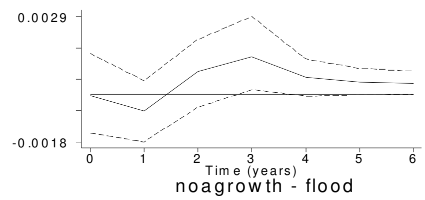
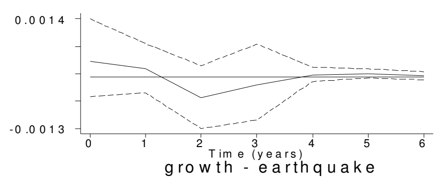
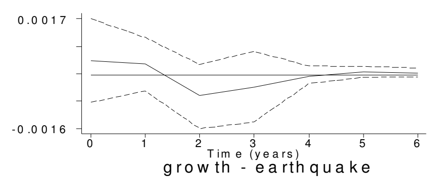


Figure 11: Effects of earthquakes on different measures of growth

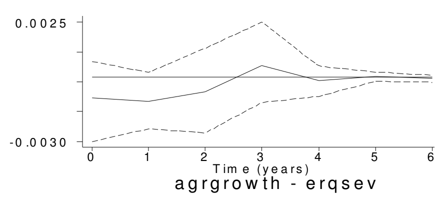
All Countries — Developing Countries

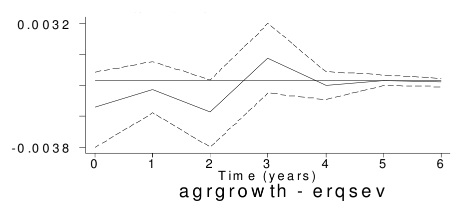
Panel (a) - Response of Growth to Earthquake Shock



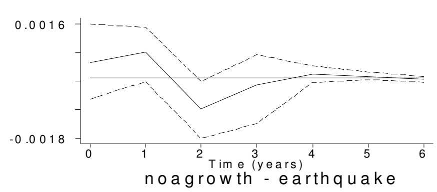


Panel (b) - Response of Agricultural Growth to Earthquake Shock





Panel (c) - Response of Non-Agricultural Growth to Earthquake Shock



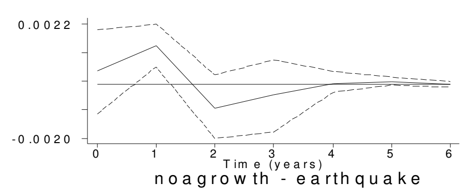
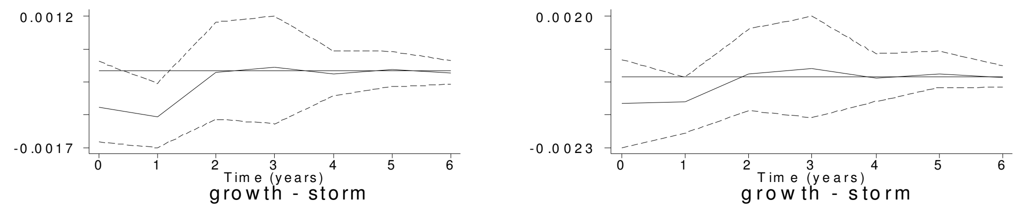


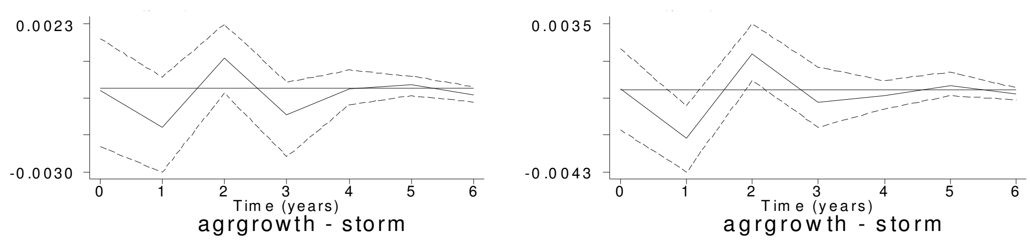
Figure 12: Effects of storms on different measures of growth

All Countries Developing Countries

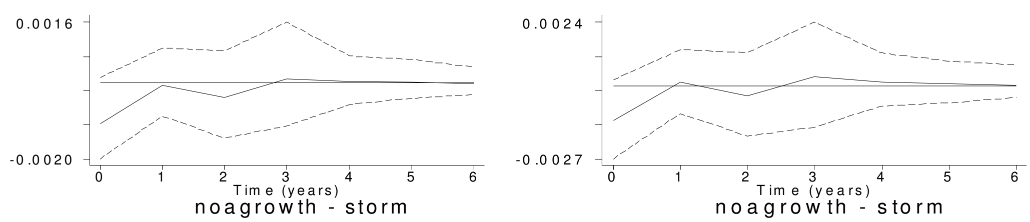
Panel (a) - Response of Growth to Storm Shock



Panel (b) - Response of Agricultural Growth to Storm Shock



Panel (c) - Response of Non-Agricultural Growth to Storm Shock



Chapter 3: Do Epidemics Hurt or Help Economic Growth?

Introduction

While in Chapter 2 I have studied the role of natural disasters in explaining economic growth, in this paper I concentrate on the growth implications of epidemics. Specifically, this paper addresses the following questions: what is the effect of epidemics (sudden health crises) on economic growth? Are all epidemics the same in their impact on economic growth? Are the effects of epidemics different in the short-run versus the long run? Answers to these questions matter for two main reasons. First, even moderate growth effects can have a huge impact on the welfare of future generations. Second, predicting the effects of these health crises is crucial to evaluating the usefulness of proposed policies to mitigate their economic effects.

These questions have become even more relevant in recent months, as many have expressed concern about the potential economic consequences of the current swine flu epidemic.[13] According to the World Health Organization, it took the A H1N1 virus less than six weeks to spread widely, while the Spanish flu in 1918 needed more than six months to spread to the same extent. This is concerning considering that Barro and Ursua (2008) identify the Spanish Flu as the fourth worst macroeconomic event since 1870. However, many economists have shown

[13] BNP Paribas, the World Bank and Brookings Institution, among others, have estimated the potential losses due to the swine flu.

skepticism with respect to the potential effects of the swine flu epidemic.[14] They argue that the swine flu is just the latest in a series of exogenous events in recent decades (including natural disasters, acts of terrorism and wars), that have had less economic impact than pessimists feared.

The channels through which an epidemic might affect economic growth are numerous. In general, studies that find a negative effect of epidemics on growth emphasize their short-run destabilizing effects on macroeconomic variables and the adverse effects that output volatility has on long-term growth. For example, the uncertainty and fear generated by an epidemic could reduce consumer confidence and could encourage people to stay at home rather than going out, to reduce the probability of infection. These effects could cause a significant reduction in private consumption spending. In addition, service exports, in particular tourism-related exports, could suffer a large decline (as happened in Mexico during the summer of 2009) while investment could be negatively affected by reduced overall demand and heightened uncertainties.

On the other hand, epidemics could generate opportunities to implement needed health care reforms, such as investment in infrastructure and health care resources, and therefore have the potential of improving long run growth performance. Imagine a poor country that lives with an endemic illness that reduces the incentives to invest in human capital because of the probability of being infected. Suppose that this country knows it needs to invest in infrastructure to fight this illness, but for political reasons, this investment is put off every year. This country

[14] See The Economist, July 23th, 2009.

may use –and perhaps needs—exogenous shocks such as epidemics as opportunities to learn, reform and improve their health care infrastructure, which may in turn enhance economic growth by increasing the incentives to invest in human capital.[15] Furthermore, if the international community sees these epidemics as caused by exogenous shocks and not by government actions, they might be willing to use Official Development Aid (ODA) and provide the necessary financing for these reforms and investment to take place. Overall, this view tends to see epidemics as a potentially desirable phenomenon in the process of development.[16]

The goal of the paper is to study the empirical association between different types of epidemics and economic growth using the Emergency Disasters Database (EM-DAT.) This database is maintained by the Center for Research on the Epidemiology of Disasters (CRED) and contains data on more than 300 epidemics during the period 1961-2005. I subject this database to a battery of econometric tests. First, in order to analyze the effect of epidemics on medium to long-run economic growth, I use pooled cross-country and time-series data covering 94 countries organized in non-overlapping five-year periods, with each country having at most 9 observations. I estimate the effect of epidemics on the growth rate of per capita GDP using ordinary least squares, controlling for unobserved country and regional-specific factors, time fixed effects and proxies for investment in human capital, financial depth, stability of monetary and fiscal policies, openness to international markets, and

[15] In this paper I have two ways of identifying epidemics: (1) either an unusual increase in the number of cases of a particular disease, which already exists in the region concerned, or (2) the appearance of a new disease in a region where it was previously absent. Note that this example belongs to the first definition.

[16] Banerjee (2009) studies which countries receive aid as insurance and why. He shows that Official Development Aid is in general pro-cyclical, but when the donor can distinguish downturns caused by exogenous shocks from those caused by government actions, aid policy is countercyclical and acts as insurance.

foreign shocks. Second, in order to addresses endogeneity problems and check the robustness of the OLS results, I use a dynamic panel GMM estimation procedure developed in Arellano and Bover (1995) and Blundell and Bond (1998). Specifically, these estimators address the econometric problems induced by country-specific effects, endogeneity, and the routine use of lagged dependent variables in growth regressions. The strategy for addressing possible omitted variable bias created by country-specific effects is to difference the regression equation. Next, we instrument the right-hand-side variables (the differenced values of the original regressors) using lagged values of the original regressors (measured in levels) as instruments. This last step removes the inconsistency arising from simultaneity bias, including biases induced by the differenced lagged dependent variable. This methodology has been used in numerous recent studies of growth [Levine, Loayza and Beck (2000); Carkovic and Levine (2005); and Loayza et al (2009)].

Next, I complement the medium term growth analysis by presenting a detailed short-run analysis of the aftermath of epidemics, tracing the yearly response of GDP growth to the onset of these events. This is a necessary step because, as the theoretical model shows, it can be the case that an epidemic has no long-run (permanent) consequences for economic growth, but generates a significant decline in the short-run followed by a recovery. Using annual data, I estimate the short-run impact of epidemics on economic growth using a panel vector auto-regression model (panel VAR). Specifically, I focus on the orthogonalized impulse-response functions, which show the response of economic growth to an orthogonal shock in epidemics. To my knowledge, this is the first time that this methodology has been used to study the short-term impact of epidemics.

As I said above, the impact of epidemics on economic growth has important policy implications. If epidemics have a negative impact on economic growth after controlling for endogeneity and other growth determinants, then this strengthens arguments for investing resources in disaster prevention and mitigation. Furthermore, it would suggest that the gap in income between low and high income countries is not only a consequence of "bad policies," but may also be the result of "bad luck." If, however, we find that epidemics do not exert a negative impact on growth, then this would suggest a reconsideration of the rapid expansion of resources invested in prevention. While no single paper will resolve these policy issues, this paper contributes to these debates.

My main finding is that different types of epidemics have different effects on economic growth. In particular I find that Cholera epidemics increase growth in the short and long run, while Influenza epidemics produce a negative effect on short-run growth, but no effect in the long-run. Furthermore, I find that the epidemics-growth relationship is robust to using instrumental variables to control for endogeneity.

My results, although new, are to some extent consistent with previous empirical findings. Many authors have studied the relationship between epidemics and economic growth, without reaching a clear consensus. A problem with most previous work is that it has mainly concentrated on the Black Death, the Spanish flu and the AIDS/HIV epidemic, which are not the right benchmark to analyze the potential consequences of the swine flu or other current events, such as the 2008-09

Cholera epidemic. The Black Death and the Spanish flu are not comparable to recent epidemics with regards to the size of the shock or data availability. The Black Death killed between 30% and 50% of the European population, while the Spanish flu killed at least 40 million people worldwide in a few months. These death tolls exceed those caused by most wars and natural disasters. These events are too large to be representative of epidemics that are likely to occur in the future. Even if we agree that the Spanish flu was important in the early 1900s, this may not be an accurate guide to the potential impact of a similar epidemic today. Most governments are now better prepared for pandemics than they were a hundred years ago. Stocks of anti-viral drugs are much greater and distribution systems are better established. A second problem with the Black Death and Spanish flu is the lack of sufficient statistical evidence to draw clear conclusions. Although data on per capita GDP and epidemics is available since the 1900s (and sometimes earlier), data for the necessary controls are only available since 1960s. Finally, we would like to know if epidemics *still* matter. To estimate the likely impact of a contemporary epidemic, we need to use more recent data, which is what I do in this paper.

The case of AIDS is also problematic, and should not be used as a benchmark for our analysis. AIDS represents a very different type of shock to the economy. An epidemic like the Swine flu can affect many victims in a matter of days, whereas AIDS evolves slowly and is associated with long periods of reduced productivity and expensive medication. In this respect, AIDS is more likely to have long run harmful effects on growth. Other differences between HIV and the epidemics considered in this paper are that HIV infection has a long latent (asymptomatic) period, affects mostly young people and has long term demographic effects through decreased fertility and healthy life expectancy. The epidemics I consider in the present work are far more contagious than the HIV virus, and the onset of the epidemic is sudden and unexpected.

On the theoretical side, standard economic theory also offers ambiguous predictions regarding the relationship between epidemics and economic growth. Assuming that epidemics represent a large negative shock to the population, the effect of such a shock on economic growth depends on the model we are considering. In the standard Solow model for example, it is clear that a once and for all negative shock to the stock of labor increases the capital per worker above its steady state level. In order to move back to the steady-state, the economy will lower investment during the following years, reducing the growth rate of GDP per capita. Meanwhile, models that explain growth by emphasizing the production of new ideas, innovation or human capital (e.g. Lucas, 1988; Romer, 1990 and Grossman and Helpman, 1991) suggest that epidemics would have a negative impact on growth by reducing the population size. Nevertheless, there are also models that predict that epidemics could potentially increase the growth rate of per capita GDP. Below I present a simple one-sector endogenous growth model, in which a negative shock to the size of the population or labor force could lead, on impact, to either an increase or decrease of per capita GDP, depending on whether it affects high skilled workers more or less than low skilled workers, and to a higher growth rate of per capita GDP in the years after the shock as a result of a faster accumulation of human capital. Later I show that this model qualitatively matches some empirical facts regarding the growth effects of epidemics.

The paper is organized as follows. Section 2 reviews the existing Literature. Section 3 presents a standard endogenous growth model and demonstrates that epidemics have an ambiguous effect. Section 4 discusses the data and methodology, presents the results and discusses their consistency with the theoretical growth model. Finally, Section 5 concludes.

Literature Review

The purpose of this paper is to examine the effects of epidemics on subsequent economic growth. There are various studies similar in spirit to my work, but different in the methodology and database used. In this section I review some of these works and reveal that they offer conflicting evidence on the relationship between population health shocks and growth. In this literature, three events have received most of the attention: the Black Death, the Spanish Flu, and AIDS. Although these events are not included in the present study, it's worth reviewing what previous works have found regarding their impact on economic growth.

The Black Death was one of the deadliest pandemics in human history, peaking in Europe between 1348 and 1350. It is believed to have been a combination of bubonic and pneumonic plagues that killed between 30% and 50% of the European population. Regarding its economic implications, the common view is that this strong decrease in the size of the working population led to a rapid increase in real wages. However, Hirshleifer (1987) argues that the impact on per capita income is less clear. Furthermore, Bloom and Mahal (1997) find a positive but insignificant effect of the plague on wages, and conclude that the evidence fails to support the hypothesis that the Black Death resulted in higher wages for the laboring classes. Perhaps as a result of data availability, the effect of the Black Death on wages and per capita income remains an unresolved issue.

The Spanish flu (1918-19) was an influenza pandemic that spread to nearly every part of the world. It was caused by an unusually virulent and deadly virus strain of subtype H1N1, the same subtype of the current Swine flu epidemic. As with the Black Death pandemic, there is no clear consensus regarding the effects of the Spanish Flu upon economic growth. There are some studies that find a negative relationship between this epidemic and economic growth. As mentioned earlier, Barro and Ursua (2008) claim that the Spanish flu was the fourth worst macroeconomic event since 1870. But there are also studies that find the Spanish Flu had a positive impact on economic growth. For example, Brainerd and Siegler (2002), using data on U.S. states for the 1919–1930 period and controlling for numerous factors including initial income, density, human capital, climate, sectoral composition of output, geography, and the legacy of slavery, find a large and robust positive effect of the influenza epidemic on per capita income growth across states during the 1920s. Consistent with these contradicting results, Bloom and Mahal (1997) are unable to find a significant relationship.

Hence, the empirical evidence on the impact of major historical epidemics is inconclusive, partly due to the lack of sufficient statistical evidence to draw clear conclusions. Although data on per capita GDP and epidemics is available since the 1900s (and sometimes earlier), data for the necessary controls are only available since

1960s. While more recent data on epidemics around the world are far from perfect, a cross-country study of these episodes appears to provide a unique opportunity to analyze the effects of epidemics on economic growth. This is the approach I take in the present paper.

Among recent epidemics, the most prominent in the economics literature is HIV/AIDS (i.e. Cuddington, 1993; Cuddington and Hancock, 1994; Bloom and Mahal, 1997). Once again, analysts disagree on the effect of AIDS on economic growth. Cuddington (1993) and Cuddington and Hancock (1994), simulating the effect of AIDS on growth in African countries, suggest that AIDS would reduce GDP by 15-25 percent and per capita income by 0-10 percent relative to a no-AIDS scenario over a 15 year period. On the other hand, Bloom and Mahal (1997), using two-stage least squares to address endogeneity problems and a database of 51 countries for the period 1980 through 1992, study the empirical correlation between AIDS incidence and per capita GDP growth, and find a statistically insignificant coefficient on the AIDS variable.

In spite of being a very interesting phenomenon worth studying, AIDS is not included in the present paper. Although the magnitude of the population shock generated by AIDS may ultimately be at least as severe as that of other epidemics, such as influenzas, the AIDS epidemic differs in important ways that likely have significant implications for its effect on economic growth. First, in contrast to the epidemic considered in this paper, which claimed victims within a matter of days of infection, AIDS is a slowly evolving disease associated with long periods of reduced productivity, high medical expenditures, and extended periods of care by family members for infected individuals. Because of these differences, I have excluded AIDS from my sample.

Motivated by concerns similar to this paper, a group of studies (many sponsored by international organizations or governmental agencies) have estimated the potential impact of epidemics. Most of them calibrate a model of a national or even the global economy, and provide a forecast under different assumptions about the gravity of the epidemic: severe (such as the Spanish Flu) or moderate (such as the 1968 Flu). For example, studying the potential effects of the current Swine flu, BNP Paribas estimates that in a severe scenario, GDP would be 4.25% lower after one year compared to what would have been observed in the absence of a pandemic, while in a mild scenario, the decline in activity could amount to about 1%.[17] McKibbin and Sidorenko (2006) estimate a global GDP impact of –0.8 per cent from a mild 1968-type pandemic and –12.6 per cent from a pandemic with population mortality roughly double that experienced in 1918. They estimate that the mortality effects of such a severe pandemic would be significantly greater in less developed countries, with GDP impacts reaching as high as 50 per cent. The U.S. Congressional Budget Office (CBO, 2005) estimates that a pandemic with population mortality double that of 1918 would reduce U.S. GDP by 5 per cent, while a 1957-type pandemic would reduce GDP by 1.5 per cent. The IMF Working Group (2006) argues that a severe pandemic could have a sharp but short-lasting impact on the economy. Bloom et al. (2005) of the Asian Development Bank estimate that a relatively mild pandemic could reduce Asian GDP by between 2.6 and 6.8 per cent, depending on the size of assumed

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[17] BNP Paribas, "*The Swine Flu Pandemic: what is the threat to recovery?*" Economic Research Group, September 2009

psychological consumption effects. Kennedy et al. (2006) of the Australian Treasury estimate that a pandemic half as severe as that of 1918 would reduce Australian GDP by 9.3 per cent. Finally, New Zealand's Treasury (2005) estimates that a severe pandemic could reduce GDP by 10 to 20 per cent in the year of impact and by 15 to 30 per cent over the medium term. These papers are very different from what I do here, in that they do not estimate the impact of previous epidemics on the growth rate of GDP, but rather quantify the potential impact of an epidemic assuming a particular model.

The paper that is closest to the present one is Raddatz (2009). Raddatz uses the same database I use to analyze the growth effects of different types of exogenous shocks, including epidemics. However, Raddatz aggregates epidemics with other types of human disasters and therefore is unable to provide an answer to my specific question. A second similarity with the present work is the use of panel-VAR on country-level variables. His attention, however, is limited to low income countries, whereas I look at countries at all levels of development.

The present paper differs from previous works in the following respects. First, it looks at the growth response of epidemics at various horizons, ranging from the initial impact to long-term, permanent effects. I do this by using both, annual data (to look at short-run dynamics) and five year averages (to look at the long-run consequences). Second, to the best of my knowledge, this is the first study to look separately at the effects of different types of epidemics. As it turns out, disaggregating is crucial to measure and interpret the growth implications of epidemics.

Conceptual framework

To analyze how different types of epidemics can affect economic growth, we have to distinguish between two different issues. First, we need to look at how the epidemic affects the composition of the population on impact. This is very important and, therefore, I dedicate the next subsection to analyze this issue. The model presented in the next subsection suggests that the implications for growth will be different if the epidemic affects relatively more skilled workers than if it affects relatively more un-skilled workers. Epidemics such as cholera and malaria, which tend to affect relatively more un-skilled workers- and therefore increase average productivity, could potentially increase the growth rate of per capita GDP, whereas epidemics such as influenzas, which do not discriminate by skill level, are less likely to have a positive effect.

Second, epidemics are health crisis and, as in most crisis, their consequences will depend on how governments and the international community react to them. A health crisis could be an opportunity to induce policy changes and institutional innovations that can ultimately be beneficial for subsequent economic growth. As I argued in the previous chapter, it is widely believed that the international community responds to events such as epidemics by increasing assistance (external aid), providing support for development and investment in infrastructure. In other words, it is essential to pay attention to how health crisis are managed. Since different types of epidemics require different responses, their implications for growth may as well be different.

For instance, Hays (2005) argues that human responses to cholera epidemics were effective at preventing future outbreaks. Prevention of cholera outbreaks entails mitigating factors such as overcrowding, inadequate housing, inadequate excreta disposal systems, lack of potable water, floods, unhygienic human behavioral practices, etc. In other words, it implies doing large investments in infrastructure to assure sustainable access to improved sanitation and water sources and observance of hygienic human behavioral practices. Not surprisingly many developed and developing nations that have done the investment have been successful at eradicating cholera epidemics. Besides the positive effects that stopping cholera may have for economic growth by improving human capital, the investment in public infrastructure could, per se, have a significant and positive impact on economic growth both in the short and long-run.

Unfortunately, this "virtuous cycle" is not present in the case of malaria epidemics. Although malaria epidemics are similar to cholera in terms of the composition of the population affected (i.e. low income, low skilled workers), attempts to eradicate it, a goal set by the World Health Organization, has had a perverse effect. Michael Alkan (2001) reports that insecticides were used in endemic areas to break the chain of transmission, but the mosquitoes developed resistance to these insecticides. As a result, malaria remains a very common affliction, making the treatment and prevention increasingly difficult. As if that were not enough, the introduction of insecticides into the ecosystem has proved to be hazardous for development, creating new diseases and having a negative effect on economic growth.

The difference between cholera and influenza epidemics is also significant in this regard. As the facts presented above illustrate, to prevent cholera epidemics investment in public health infrastructures is much more important than the biomedical response (no vaccine that has been effective at controlling cholera outbreaks). The opposite is the case for influenza epidemics. Brainerd and Siegler (2002) argue that differences in public health services cannot explain variation in mortality rates from influenza epidemics across countries and states in the US, and that most public health measures are completely ineffective at stopping the disease. On the contrary, it has been shown (see Alkan 2001) that when most of the population carries protective antibodies, the epidemic subsides. This immunization is achieved by developing and distributing vaccinations. As opposed to the case of cholera epidemics, in spite of the positive effect that may have for the society, stopping an influenza epidemic is less likely to increase growth in the short run because no large investment in infrastructure is involved.

A simple model of Economic Growth and Epidemics

In order to have a better understanding of the theoretical implications of epidemics for economic growth, in this section I present a canonical model of endogenous growth based on Barro and Sala-i-Martin (2004, Chapter 5) and Gomez (2003). The main purpose of this section is to show that economic theory offers ambiguous predictions regarding the relationship between negative population shocks (such as epidemics) and the growth rate of GDP per capita. The model is standard so I skip many details, which the interested reader can find in Barro and Sala-i-Martin (2004) or Gomez (2003).

One-sector Endogenous Growth Model with Physical and Human Capital

In this economy there is a benevolent social planner that allocates resources in order to maximize lifetime utility of the representative household:

$$\int_0^\infty u(c_t)e^{-\beta t}dt, \qquad (3.1)$$

where c_t is consumption per person and $\beta>0$ is the time discount rate. I also assume that $u(c)=\frac{c^{1-\theta}-1}{1-\theta}$ is a CRRA function, where θ represents the inverse of the inter-temporal elasticity of substitution. The economy produces a single final good, Y, using a Cobb-Douglas production function that exhibits constant returns to scale to physical and human capital:

$$Y_t = A_t K_t^{\alpha}(h_t N_t)^{1-\alpha},$$

where $0<\alpha<1$, K is the aggregate stock of physical capital, N is the number of workers (which equals the size of the population,) and h is the average level of human capital of the workers. For instance, we could think of h as the total number of skilled workers (engineers, doctors, etc) divided by the total number of workers ($h=H/N$). To simplify the algebra, I assume that the level of technology A is constant.

Since the purpose of this paper is to study the impact of epidemics on the growth rate of GDP per capita, in order to have theoretical predictions it is necessary to write the problem in per capita terms. Using lower case letters to denote a variable in per capita terms, the production function can be written as

$$y_t = Ak_t^{\alpha} h_t^{1-\alpha}. \qquad (3.2)$$

The model assumes that output can be used for consumption or investment in physical or human capital. For simplicity once again, I assume that physical and human capital depreciate at the same rate, δ. The depreciation of human capital includes losses from skill deterioration and mortality of skilled workers.

The economy's resource constraint is

$$y_t = c_t + i_t^K + i_t^H, \qquad (3.3)$$

and the dynamic equations for the accumulation of physical and human capital are:

$$\dot{k}_t = i_t^K - \delta k_t, \qquad (3.4)$$

$$\dot{h}_t = i_t^H - \delta h_t. \qquad (3.5)$$

The social planner's problem is to maximize (3.1) subject to the constraints (3.2), (3.3), (3.4), (3.5) and the non-negativity constraints $i_t^K \geq 0; i_t^H \geq 0$. The current value Hamiltonian is:

$$J = \frac{c_t^{1-\theta} - 1}{1-\theta} + \lambda\left[Ak_t^{\alpha} h_t^{1-\alpha} - c_t - i_t^K - i_t^H\right] + \mu_1\left[i_t^K - \delta k_t\right] + \mu_2\left[i_t^H - \delta h_t\right],$$

where λ, μ_1 and μ_2 are Lagrange multipliers for (3.3), (3.4) and (3.5) respectively. The first order conditions (FOC) of the problem are:

$$c_t^{-\theta} = \lambda,$$

$$\lambda \geq \mu_1; \lambda \geq \mu_2,$$

$$\frac{\partial J}{\partial k} = -\dot{\mu}_1 + \beta\mu_1 = \lambda\alpha Ak_t^{\alpha-1} h_t^{1-\alpha} - \mu_1\delta,$$

$$\frac{\partial J}{\partial h} = -\dot{\mu}_2 + \beta\mu_2 = \lambda(1-\alpha)Ak_t^{\alpha} h_t^{-\alpha} - \mu_2\delta,$$

The First order conditions imply that, at an interior solution, the net returns on physical and human capital must be equal

$$\alpha A k_t^{\alpha-1} h_t^{1-\alpha} = (1-\alpha) A k_t^{\alpha} h_t^{-\alpha}.$$

Thus, at an interior solution, the ratio of physical to human capital is constant over time:

$$\frac{k}{h} = \frac{K}{H} = \frac{\alpha}{1-\alpha}.$$

Also, from the FOC we can derive the following dynamic equation:

$$\gamma = \frac{\dot{c}}{c} = \frac{1}{\theta}[A(1-\alpha)\left(\frac{K}{H}\right)^{\alpha} - (\beta + \delta)].$$

I assume that the parameters are so that $\gamma > 0$. It is readily shown that *c, k, h* and *y* must all grow at the same constant rate γ.

Effect of an epidemic shock

I now analyze the effect of an epidemic on the growth rate of output per capita. I look first at the path of growth right after the epidemic, and then explain what happens to output per capita at the moment of the shock.

Potentially, there is more than one way in that an epidemic could affect the economy.[18] Here I assume that an epidemic will destroy (kill) workers, among which there will be some skilled workers and some unskilled workers, and have no effect on physical capital. Hence, if the epidemic strikes at time t=0, then $\frac{K_0}{H_0} > \frac{\alpha}{1-\alpha}$ so that *k* will be abundant relative to *h*, and its marginal productivity will thus be lower than

[18] For example, the epidemic could also affect the growth rate of the population.

the marginal productivity of human capital. If there were no non-negativity constraints, the adjustment would entail immediately increasing *h* and decreasing *k* by discrete amounts so that the ratio of physical to human capital would remain at its steady state value $\frac{K}{H}=\frac{\alpha}{1-\alpha}$, with all variables growing at the same constant rate γ thereafter. However, this solution requires negative gross investment in physical capital at an infinite rate, and we have assumed that investment must be non-negative. The desire to reduce *k* implies that the inequality $i_t^K \geq 0$ will be binding during the transition to the steady state, whereas $i^h>0$. As the economy evolves the ratio of physical to human capital will decrease until the returns on both factors are equalized.

It can be shown that during the transition GDP per capita grows at a higher rate than along the balanced growth path.[19] The growth rate immediately following the initial impact of the shock will satisfy:

$$\gamma_c^{Transition}=\frac{1}{\theta}\left[A(1-\alpha)\left(\frac{K_0}{H_0}\right)^{\alpha}-(\beta+\delta)\right]>\frac{1}{\theta}\left[A(1-\alpha)\left(\frac{\alpha}{1-\alpha}\right)^{\alpha}-(\beta+\delta)\right],$$

and $$\gamma_y^{Transition}=(1-\alpha)A\omega^{\alpha}-\chi-\delta,$$

where ω=k/h and χ=c/h.

Barro and Sala-i-Martin (1995)[20] show that during the transition ω decreases monotonically to its balanced path value $\omega^*=(\alpha/1-\alpha)$, and χ increases monotonically, which means that γ_y is decreasing monotonically. Since γ_y falls monotonically toward $\gamma^*>0$, it must be positive, but declining during the transition. This result implies that

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[19] See Gomez (2003) for a detail exposition of the dynamics during the transition
[20] See Barro and SAla-i-Martin (1995, pp. 176-203)

the growth rate of output, γ_y, is positively related with the ratio ω=k/h. Thus, there is an imbalance effect: the greater the epidemic shock, the higher the growth rate.

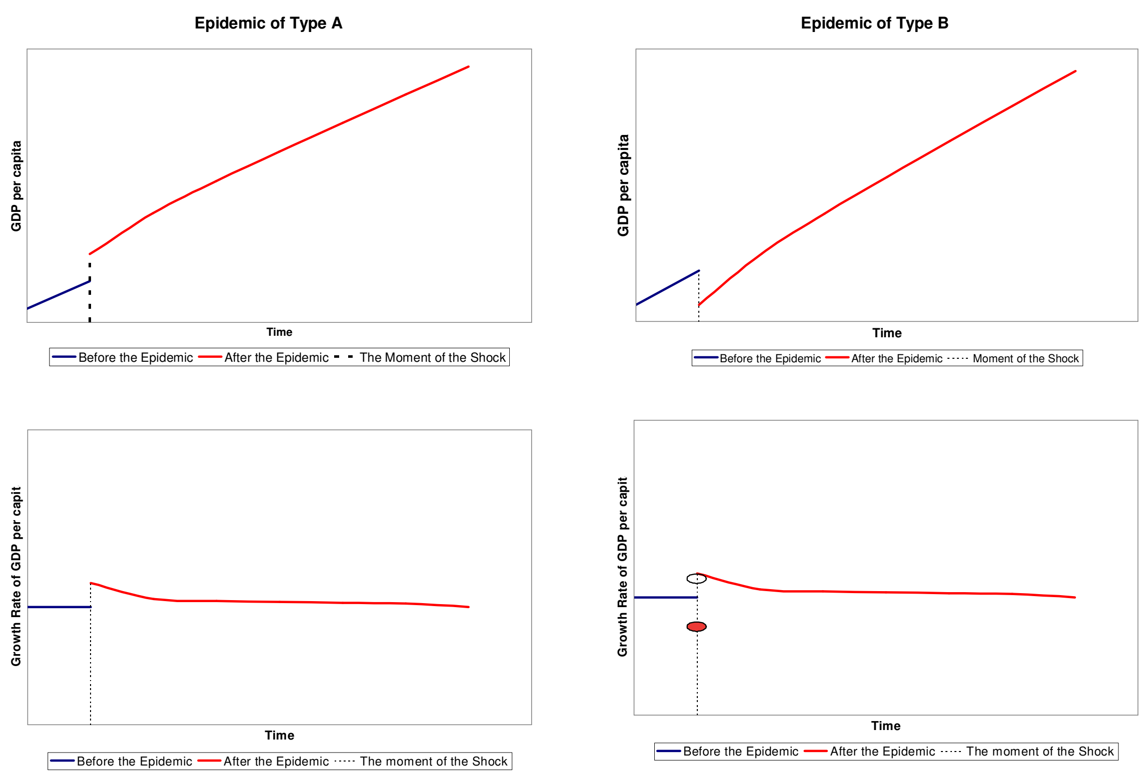
In summary, in the short and medium-run, the economy responds to the epidemic with a massive accumulation of human capital in order to catch up with physical capital. This accumulation of human capital generates an increase in the growth rate of per capita GDP. Gomez (2003) shows that this regime prevails until the returns to both types of capital are equalized, and that this happens in a finite period of time. In summary, if this model is right, we should see an increase in the growth rate of per capita GDP in the aftermath of epidemics. However, we still need to see what happens to per capita GDP at the moment of the shock.

The next step is to determine what happens to output per capita (*y*) at the moment of the epidemic. I argue that the effect will depend on the type of epidemic. As I show in Figure 1, epidemics that affect skilled workers more than unskilled workers could potentially reduce per capita GDP on impact, while epidemics that mainly affect unskilled workers, will generate a jump (increase) in per capita GDP.

To understand the intuition for these results, we should first remember that $k=K/N$ and $h=H/N$, where *K* is the aggregate stock of physical capital, *H* is the aggregate stock of skilled workers and *N* is the total number of workers (or the size of the population). We would expect the epidemic to reduce the total stock of labor (*N*) and the aggregate stock of human capital (*H*), but have no impact on physical capital. So there are two issues to consider here. On the one hand, there is no doubt that the stock of capital per worker (*k*) would increase, but on the other hand, the effect of a typical epidemic on average human capital (*h*) is not clear, since it depends on the relative responses of: the total stock of labor (*N*) and the aggregate stock of human capital (*H*). There is some evidence that epidemics typically affect unskilled workers more than they affect skilled workers (see Brainerd and Siegler, 2003). In other words, the typical epidemic increases average human capital per worker (*h*). This means that output per worker jumps up at the moment the epidemic occurs.

But, there is also evidence that some particular types of epidemics affect skilled workers more than unskilled workers (see Crosby, 2003). In particular, Influenza epidemics affect skilled workers more so than other types of epidemics. If this is the case, at the moment of the shock we would see a decrease in average human capital (h). If the decrease in h is strong enough to outweigh the increase in physical capital per worker, we would see a decrease in per capita GDP upon impact, which would cause a decrease in the growth rate for that year (see Figure 1).

Figure 1: Effect of Epidemics



In summary, the implications of the one sector model are, to some extent, surprising. The model suggests that epidemics have the potential to enhance development. As we can see in Figure 1, for epidemics that affect unskilled workers more than skilled workers, the model predicts an instantaneous increase in output and consumption per worker followed by higher growth during the transition to the steady state. For the case of epidemics that affect skilled workers more than unskilled workers, the model predicts an initial decrease in GDP per capita and its growth rate, followed by a fast recovery. Hence, I argue that the effect of epidemics on economic growth is an empirical question. The empirical analysis is what we do next.

The theoretical predictions discussed above have important implications for my empirical study. First, for the medium and long-run analysis that uses five year averages, we should expect a positive relationship between epidemics affecting primarily unskilled workers (shown in panel b of Figure 1 as Type A) and the growth rate of per capita GDP. However, for epidemics that primarily affect skilled workers (Shown in panel a), the prediction is not as clear, and thus the relationship is less likely to be significant. Second, for the short-run analysis, using annual data we should expect that epidemics of type B reduce growth in the short-run, while epidemics of type A should increase growth.

Data, Methodology and Empirical Results

This paper studies the growth effects of epidemics in the short-run and on long-run using two very different methodologies. To make the analysis more tractable, I present the methodologies and results in separate sub-sections. But first, section 4.1 presents a brief description of the EM-DAT database and some facts about the types of epidemics considered. Next, I present the methodology and results of the medium to long run analysis and the short run analysis.

Database and facts about epidemics

In this sub-section I provide a brief description of the EM-DAT database and present some facts about the types of epidemics considered.

EM-DAT is a worldwide database on disasters maintained by CRED with the sponsorship of the United States Agency for International Development's Office of Foreign Disaster Assistance (OFDA). It contains data on the occurrence and effects of more than 17,000 natural disasters and epidemics in the world from 1900 to the present. The database is compiled from various sources, including UN agencies, non-governmental organizations, insurance companies, research institutes and press agencies.

CRED defines an epidemic as "*either an unusual increase in the number of cases of a disease, which already exists in the region or population concerned, or the appearance of an infection previously absent from a region*." EM-DAT only considers situations or events which overwhelm local capacity, necessitating a request at the national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering. For an event to be entered into the database, at least one of the following criteria must be fulfilled:

10 or more people reported killed; 100 or more people reported affected; declaration of a state of emergency; or a call for international assistance.

CRED divides epidemics according to type (for example: cholera, malaria, influenza, etc), and provides the dates when the epidemic occurred and ended; the number of casualties (people confirmed dead) and the number of people affected (requiring immediate medical treatment as a direct result of the epidemic). Next, I present some facts about each type of epidemic considered in the study.

Arbovirus

Arbovirus is a shortened name given to viruses that are transmitted by arthropods, or arthropod-borne viruses, which include Yellow fever, Dengue, Ebola, Japanese encephalitis, Haemorrhagic fever and some other diseases. In my sample there are 89 epidemics belonging to this category. They affect on average 10,000 people and have a mortality rate of 1.13%. Most of these epidemics (95%) have taken place in middle and low income countries, while only 4% of them have affected high income countries. With respect to geographic areas, almost 70% of them took place either in Latin America or South Asia, while around 30% of them occurred in Sub-Saharan Africa and East Asian & Pacific region.

Cholera

Cholera is an infectious gastroenteritis caused by enterotoxin-producing strains of the bacterium *Vibrio cholerae*. Although cholera is life-threatening, prevention of the disease is normally straightforward if proper sanitation practices are followed. In high income countries, due to nearly universal advanced water treatment and sanitation practices, cholera is no longer a major health threat. As shown in Figure 1, only 0.7% of the cholera epidemics in my sample took place in advanced nations. But Cholera still heavily affects populations in developing countries (99% of the cases in my sample) due to deficiencies in filtering and chlorination of water supplies. Among the developing world, more than 50% of the epidemics in the sample took place in Sub-Saharan Africa (see Figure 2). The other regions with most outbreaks were South Asia (19.4%) and Latin America (17%). The outbreak in South America during the first years of the 1990's began in Peru and eventually led to 1.04 million identified cases and almost 10,000 deaths.

Cholera exists as a seasonal disease in many endemic countries, occurring annually mostly during rainy seasons, however, these cases are not included in my sample. Cholera epidemics are included in the sample only if there is either an unusual increase in the number of cases of the disease, which already exists in the region concerned, or when it appears in a region where it was previously absent. For example, the most recent epidemic is the 2008 Zimbabwean cholera outbreak, which is still continuing. In this epidemic, an estimated 96,591 people in the country have been infected with cholera and, by 16 April 2009, 4,201 deaths had been reported.

Malaria

Malaria is one of the most common infectious diseases and an enormous public health problem. Malaria is an endemic problem in many countries generating approximately 350–500 million cases annually, killing between one and three million people, the majority of whom are young children in Sub-Saharan Africa. However, as in the case of cholera, my sample includes a malaria epidemic only when there is an unusual increase in the number of cases of the disease, which already exists in the region concerned, or if it appears in a region where it was previously absent. Only 39 events satisfy this definition. More than 40% of malaria-epidemics took place in Sub-Saharan Africa, 31.6% in South Asia and the other 25% distributed between East Asia & Pacific and Latin America (see Figure2). The main reason for including Malaria as a separate epidemic in our study is that is commonly associated with poverty, but is also a cause of poverty and it is considered to be a major impediment to economic development.

Influenza

Influenza, commonly referred to as the flu, are infectious diseases caused by RNA viruses of the family Orthomyxoviridae (the influenza viruses), which affect birds and mammals. According to the World Health Organization (WHO), evolutions in influenza viruses cannot be predicted. This makes it difficult to know if or when a virus might become easily transmittable among humans. The WHO indicates that accurate predictions of mortality cannot be made before a pandemic virus emerges and begins to spread.

Every winter, tens of millions of people get the flu and a few hundred thousand people die every year. But once again, as for cholera and malaria, influenza epidemics are included in the sample only if there is either an unusual increase in the number of cases of the disease which already exists in the region concerned, or when it appears in a region where it was previously absent.

Influenzas are really a global phenomenon. There is a clear difference between influenzas and other types of epidemics in how they are distributed around the world. As we can see from Figure 2, influenzas affect high income countries as much (or perhaps more) as they affect low and middle income countries. In the sample of epidemics used in this study, almost 37% of the influenzas considered have affected high income countries, whereas less than 30% of them have affected low income countries.

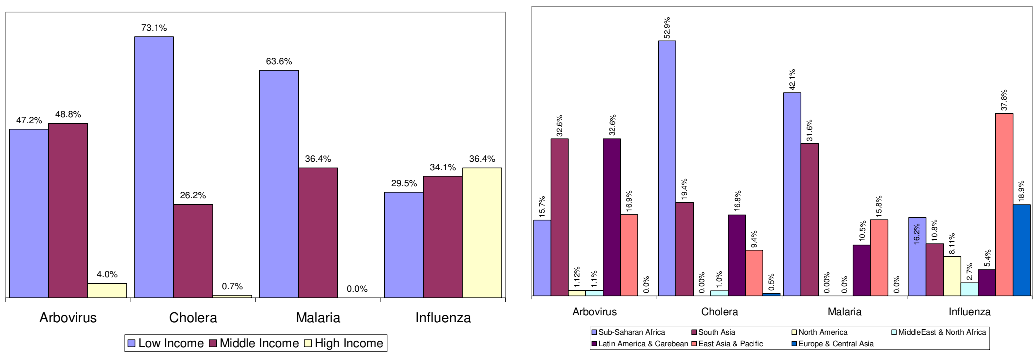
In a typical influenza epidemic the majority of the victims are young children and the elderly, giving the age profile of mortality a distinct 'U' shape. However, this is not the case in all epidemics. A distinguishing characteristic of the 1918 epidemic was that it disproportionately killed men and women age 15 to 44, so that the age profile of mortality instead followed a 'W' pattern. Also, some observers (e.g. Crosby, 1989 and Rice, 1988) argue that the socioeconomic status of influenza victims indicates few differences in mortality rates across income groups, and that people from high income groups have a higher probability of being infected and spread the disease to different countries when they travel for business or tourism. Since people at higher levels of income are generally associated with high skill levels, I take this as evidence suggesting that an influenza epidemic may affect skilled workers more than unskilled workers. As I showed in the previous section, this could cause the impact of influenzas on economic growth to differ from other epidemics.

The current Swine Flu Epidemic

In April 2009 a novel flu strain evolved that combined genes from human, pig, and bird flu. This strain, initially dubbed "swine flu" and also known as influenza A/H1N1, emerged in Mexico, the United States, and several other nations. The World Health Organization officially declared the outbreak to be a "pandemic" on June 11, 2009. The WHO's declaration of a pandemic level 6 was an indication of spread, not severity. According to the World Health Organization, it took the A/H1N1 virus less than six weeks to spread widely, while previous flu pandemics in 1918, 1957 and 1968 needed more than six months to spread to the same extent. As a result of spreading concern about this outbreak, President Barak Obama declared a sate of National Emergengy on October 24th of 2009. Concerns have been voiced regarding the potential macroeconomic consequences (i.e. BNP Paribas (September, 2009) and World Bank (June, 2009)).

Figure 2: Distribution of different types of epidemics by:

a. Level of Development **b. Region of the World**



Source: Author's own calculations using data from EM-DAT. The division by level of development and region of the world comes from World Development Indicators.

Estimating the medium to long-run impact of epidemics

This section studies the effect of epidemics on the medium to long-run economic growth rate of the aggregate economy. I use pooled cross-country and time-series data covering 94 countries over the period 1961-2005. The data is organized in non-overlapping five-year periods, with each country having at most 9 observations. In order to check the robustness of the results using OLS, I build on the panel-data growth regression literature and use a GMM procedure to address endogeneity and to control for unobserved country-specific factors, as presented for example in Loayza, Olaberria, Rigolini and Christensen (2009). Further details on the system GMM methodology are given in the appendix.

Data and Regression Specification

The point of departure is a growth regression equation designed for estimation using (cross-country, time-series) panel data:

$$y_{i,t} - y_{i,t-1} = \beta_0 y_{i,t-1} + \beta_1 CV_{i,t} + \beta_2 EP_{i,t} + \mu_t + \eta_i + \theta_j + \varepsilon_{i,t} \qquad (4.2.1)$$

Where the subscripts i and t represent country and time period, respectively; y is the log of output per capita, *CV* is a set of control variables, and *EP* represents the incidence of epidemics; μ_t, η_i and θ_j denote unobserved time-, country- and regional-specific effects, respectively; and ε is the error term. The regression equation is dynamic in the sense that it includes the level of output per capita at the start of the corresponding period in the set of explanatory variables.

The dependent variable is the average annual rate of real output growth (i.e., the log difference of output per capita normalized by the length of the period). Data for output was obtained from the World Bank's World Development Indicators (WDI 2007).

I divide the set of growth determinants in three groups. The first group is composed of variables that measure transitional convergence, structural policies, institutions and stabilization policies. The second set of variables proxies the role of external conditions that may affect the growth performance across countries. Finally, I pay special attention to epidemics, which represent the subject matter of the paper.

To control for transitional convergence, we use the initial value of output per capita (in logs) for the five-year period. This variable allows me to test whether the initial position of the economy is important for its subsequent growth, all things equal.

With respect to structural policies and institutions, I consider measures of education and human capital, financial development, monetary and fiscal policy and trade openness. Education is proxied by the gross rate of enrollment in secondary school, which is the ratio of the number of students enrolled in primary school to the number of persons of the corresponding age. Financial depth is measured as the ratio of domestic credit to GDP. Our first proxy of macroeconomic stabilization is the consumer price index (CPI) inflation rate, with high inflation being associated with bad macroeconomic policies. In addition, I measure the government burden as the ratio of general government consumption to GDP. Finally, I include a measure of trade openness, namely the volume of trade (exports and imports) over GDP. For all these variables, the source of information is the World Bank (WDI 2007).

With regard to external variables, the regressions include terms of trade, to capture shifts in the demand for a country's exports and period- and regional-specific dummies, which capture the impact of other global and regional trends of growth across countries. All these data are from the World Bank (WDI 2007).

My most important variables proxy the impact of epidemics on growth. As explained above, data for epidemics was obtained from the Emergency Disasters Database (EM-DAT), maintained by the Center for Research on the Epidemiology of Disasters (CRED). In particular, for each epidemic I measure the size of the disaster as the log of the sum of the total number of people affected over the five -year period, divided by the total population. Formally, $EP_{i,t} = Log\left(\sum_j \frac{Total\ Affected_{i,t,j}}{Population_{i,t}} \right)$ where j indexes the number of events that took place in country *i* during (five-year) period *t*. By considering the sum of the number of people affected per event, the measure explicitly accounts for both the *frequency* and the *intensity* of epidemics, contrary to many of the measures used in the literature. To enable comparison across countries, further normalization by the total population is undertaken to correct for differences in population size.

Inspection of the distribution of the weighted sum of epidemics shows that it is positively skewed. Consequently the log is taken to avoid that the empirical results are driven by extreme values. Observations for which no event has been reported over a five year period are assigned a value of to -20, which is just below the lowest observation for which an event was reported.[21]

Finally, the regression presented above poses some challenges for estimation. The first is the presence of unobserved period- and country-specific effects. While the inclusion of period-specific dummy variables can account for the time effects, the common methods of dealing with country-specific effects (that is, within-group or difference estimators) might be inappropriate given the dynamic nature of the regression. The second challenge is that most explanatory variables are likely to be jointly endogenous with economic growth, so we need to control for the biases resulting from simultaneous or reverse causation. Although epidemics are assumed exogenous their effects would be incorrectly estimated if the endogeneity of the remaining variables in the model is ignored. In the following paragraphs we present a brief explanation of the econometric methodology used to control for country-

[21] This number has been (arbitrarily) chosen to be low enough not to affect the distribution of the epidemic indicator.

specific effects and joint endogeneity in a dynamic model of panel data (see the Appendix for more details on the methodology).

To control for country-specific effects and joint endogeneity, I use the generalized method of moments (GMM) estimators developed for dynamic models of panel data that were introduced by Holtz-Eakin, Newey, and Rosen (1988), Arellano and Bond (1991), and Arellano and Bover (1995). These estimators are based, first, on differencing regressions or instruments to control for unobserved effects and, second, on using previous observations of explanatory and lagged-dependent variables as instruments. The method deals with unobserved time effects through the inclusion of period specific intercepts. Dealing with unobserved country effects is not as simple given the possibility that the model is dynamic and contains endogenous explanatory variables. Unobserved country effects are controlled for by differencing and instrumentation.

Likewise, the method relies on instrumentation to control for joint endogeneity. Specifically, it allows relaxing the assumption of strong exogeneity of the explanatory variables by allowing them to be correlated with current and previous realizations of the error term. Parameter identification is achieved by assuming that future realizations of the error term do not affect current values of the explanatory variables, that the error term is serially uncorrelated, and that *changes* in the explanatory variables are uncorrelated with the unobserved country-specific effect. As Arellano and Bond (1991) and Arellano and Bover (1995) show, this set of assumptions generates moment conditions that allow estimation of the parameters of interest. The instruments corresponding to these moment conditions are appropriately lagged values of both levels and differences of the explanatory and dependent variables (the latter if the model is dynamic).

The consistency of the GMM estimators depends on whether lagged values of the explanatory variables are valid instruments in the regression. We address this issue by considering two specification tests. The first is the Hansen test of overidentifying restrictions, which tests the validity of the instruments by analyzing the sample analog of the moment conditions used in the estimation process. Failure to reject the null hypothesis gives support to the model. The second test examines whether the original error term is serially correlated. The model is, therefore, supported when the null hypothesis is not rejected. In the system specification, I test in fact whether the first-differenced error term (that is, the residual of the equation in differences) is second-order serially correlated. First-order serial correlation of the differenced error term is expected even if the original error term (in levels) is uncorrelated, unless the latter follows a random walk. Second-order serial correlation of the differenced residual indicates that the original error term is serially correlated and follows a moving average process of at least order one.

Results

The estimation results are presented in Tables 1-3. In all Tables, the dependent variable is the growth rate of GDP per capita. For ease of exposition, the four tables follow a symmetric pattern. The first column considers all epidemics aggregated into a single index. The next four columns report results from specifications including one particular epidemic and an aggregate of all other epidemics. The set of explanatory variables always includes the same control variables.

To establish the validity of my results in the context of the growth literature, I start by analyzing the results corresponding to the standard growth determinants. Table 1 presents OLS results. In brief, the coefficients on controls are consistent with the previous empirical literature. Initial GDP per capita carries a significantly negative coefficient, commonly interpreted as evidence of conditional convergence. The proxies of education, financial depth, and trade openness have positive and significant coefficients, denoting their beneficial impact on economic growth. Government consumption and price inflation, on the other hand, carry negative coefficients, indicating the harmful consequences of a large fiscal burden and macroeconomic price instability. External shocks are also important growth determinants. More favorable terms of trade positively affect economic growth. The period dummies (not shown in the tables to save space) indicate that international economic growth experienced a declining trend over 1960-2000, resulting in less favorable external conditions in the 1980s and 1990s than in previous decades. Finally, for the case of the system GMM methodology I need to look at the specification tests. The Hansen and serial-correlation tests indicate that the null hypothesis of correct specification cannot be rejected, lending support to our estimation results. This is also the case for the remaining exercise presented below, and I only mention it here in order to avoid redundancy.

Next, I turn to the growth effects of epidemics. I simply describe the results in this section and leave the explanation of them for the next section, when the results of the short-run analysis are presented. The combined index of epidemics carries a negative but not statistically significant coefficient. The lack of a significant effect reflects well the theoretical ambiguity of standard growth models. The remaining columns disaggregate the epidemics index to disentangle this ambiguity. Individual epidemics have contrasting effects on growth: while Arbovirus and Influenza epidemics appear to produce lower growth (although not significantly), Cholera epidemics seem to lead to significantly higher growth. Malaria epidemics also appear to have a positive growth effect, but the effect is statistically insignificant. These results hold for both samples (All Countries and Developing Countries), and for both methodologies (OLS and System GMM). Hence, it appears that the positive effect of cholera epidemics on long-run economic growth is robust.

Are the effects of epidemics on economic growth quantitatively important?

Here, as in Chapter 2, I ask whether the effect of epidemics is important quantitatively. The answer to this question is illustrated in Chart 1, which presents the estimates of the growth effect of a typical epidemic. The calculations are made using the point estimates of the coefficients, presented in Table 1 and 2

.**Chart 1**

Quantitative effect of epidemic on the Growth Rate of GDP pc

Epidemic	OLS	System GMM
Arbovirus	-0.15	-0.25
Cholera	0.83 ***	0.69 ***
Malaria	0.31	0.04
Influenza	-0.39	-0.45

I concentrate on the effects of cholera epidemics, because cholera is the only significant epidemic in the regressions. A typical cholera epidemic produces an increase of annual growth rate of GDP per capita of between 0.7 and 0.83 percentage points depending on the methodology considered. Hence, I conclude that the quantitative effect of cholera is of a very significant magnitude.

Estimating the short-run impact of epidemics

To study the effect of epidemics on economic growth in the short run, I use pooled cross-country and annual time-series data covering 94 countries over the period 1961-2005. The panel is unbalanced, with some countries having more observations than others.

The variables used in this section are a sub-set of the ones used in the medium and long-run analysis. The dependent variable is the growth rate of real per capita Gross Domestic Product (GDP). To capture external conditions that may affect short-run growth, I control for the growth rate of the country's Terms of Trade (TOT), to capture shifts in the demand for a country's exports. As before, data for these variables were obtained from the World Bank (WDI, 2007). The last set of variables measures the impact of epidemics on growth. Throughout the exercise, I assume that epidemics are exogenous with respect to the growth variables and shocks to terms of trade.

Methodology

I study the short-run effect of epidemics using the panel data Vector Autoregression (VAR) methodology. This technique combines the traditional VAR approach, which treats all the variables in the system as endogenous, with panel-data techniques alowing for unobserved individual heterogeneity.[22] Here I present a brief decription and the main intuition of the methodology.

I specify a first-order three-variable VAR model as follows:

$$z_{i,t} = \sum_{s=1}^{q} \Phi_s z_{i,t-s} + f_i + \varepsilon_{it}$$

where $z_t=[z_{1t} \quad z_{2t} \quad z_{3t}]$; and where z_{1t} is the number of epidemics, z_{2t} represents terms of trade shocks and z_{3t} is the growth rate of GDP per capita, which is my main variable of interest.

I focus the analysis on the impulse-response functions, which describe the reaction of one variable in the system to the innovations in another variable in the system, holding all other shocks at zero. However, since the actual variance-covariance matrix of the errors is unlikely to be diagonal, to isolate shocks to one variabvle it is necessary to decompose the residuals in such a way that they become orthogonal. The usual convention is to adopt a particular ordering and allocate any correlation between the residuals of any two elements to the variable that comes first in the ordering. The identifying assumption is that the variables that come earlier in the ordering affect the later variables contemporaneously, as well as with a lag, while

[22] For a detailed discussion of the standard panel VAR model and the computation of impulse-response functions see Love and Lea (2002).

the variables that come later only affect the earlier variables with a lag. Following this convention, I assume that:

- Epidemics shocks have contemporaneous effects on GDP growth rates and terms of trade shocks;
- Terms of trade shocks have contemporaneous effects on GDP growth rates; but not on epidemics;
- GDP growth shocks do not have any contemporaneous effect on the other two variables

In applying the VAR procedure to panel data, I need to impose the restriction that the underlying structure is the same for each cross-sectional unit. Since this constraint is likely to be violated in practice, one way to relax the restriction on parameters is to introduce fixed effects. Since the fixed effects are correlated with the regressors due to lags of the dependent variables, the mean differencing procedure commonly used to eliminate fixed effects will create biased coefficients. To avoid this problem I use forward mean-differencing, also referred to as the Helmert procedure (see Arellano and Bover 1995). This procedure removes only the forward mean, i.e. the mean of all the future observations available for each country-year. Since this transformation preserves the orthogonality between transformed variables and lagged regressors, we use lagged regressors as instruments and estimate the coefficients by system GMM (see Appendix for more details).

To analyze the impulse-response functions I need some estimate of their confidence intervals. Since the matrix of impulse-response functions is constructed from the estimated VAR coefficients, their standard errors need to be taken into account. Hence, I use Monte Carlo simulation to generate their confidence intervals of the impulse response functions.

Results

I now report and discuss the main results on the growth consequences of natural disasters. I organize the presentation by type of epidemic –arbovirus, cholera, malaria, and influenzas. For each type of epidemic, I present impulse responses for its effect on real per capita GDP growth. I first estimate these effects using the sample of all countries. Then, I estimate these effects using the sample of developing countries only. Impulse responses are presented in Figures 3 to 6, along with 90% confidence intervals.

Figure 3 shows impulse-responses function of GDP growth to an Arbovirus shock both for the sample of All Countries and for Developing Countries only. Contrary to the insignificant results from the long-run analysis, Arbovirus now has a significant negative effect on GDP growth. This effect is strongest in the year following the shock, and it is slightly larger in developing countries.

Next, Figure 4 shows that cholera epidemics tend to have a positive effect on economic growth. This confirms the results found in the long-run analysis. The mean response of the growth rate of GDP per capita to a cholera shock is positive and significant a few years after the event. The timing of the impulse response suggests that cholera does not affect per capita GDP on impact, but only with a lag. One explanation for these results is that cholera epidemics generate opportunities for needed but costly reforms to take place, such as investment in public health infrastructure which in turn have the potential of improving long run growth performance. To understand the logic of this argument, we need to go back to the stylized facts presented above. In many poor countries cholera is an endemic disease, which might affect long-run incentives to invest in human capital because of the probability of being infected. Suppose that this country knows it needs to invest in infrastructure to fight this illness, such as advanced water treatment facilities and sanitation practices, such as filtering and chlorination of water supplies, but for political reasons, this investment is put off every year. This country may use –and perhaps needs— an exogenous shock such as a cholera epidemic to force it to improve its health care infrastructure. Furthermore, if the international community sees these epidemics as caused by exogenous shocks and not by government actions, they might be willing to use Official Development Aid (ODA)[23] and provide the necessary financing for these reforms and investment to take place. These developments may in turn enhance economic growth in the short-run as a result of the increase in investment, and also generate an increase in long-run growth by increasing the incentives to invest in human capital. This might be why we find that cholera epidemics increase growth with lag (it takes a few years for the investments to begin) in the short-run analysis, and also why we find cholera to increase growth permanently in the long-run analysis.

Next, Figure 5 plots the impulse response of growth to Malaria. These epidemics are weaker in terms of statistical significance than in the case of Arbovirus and Cholera. Finally, I find that influenza type epidemics have similar dynamic

[23] Banerjee (2009) studies which countries receive aid as insurance and why. He shows that Official Development Aid is in general pro-cyclical. However, when the donor can distinguish downturns caused by exogenous shocks from those caused by government actions, aid policy is countercyclical and acts as
insurance in response to exogenous shocks.

effects as Arbovirus. As we can see in Figure 6, the mean response of the growth rate of real per capita GDP to an influenza shock is negative during the second and third year of the epidemic, but then becomes insignificant.

How can we explain these results in light of the theoretical model presented above? Remember that our theoretical model predicts that some epidemics, those that affect skilled workers relatively more than unskilled workers would generate an initial decrease in per capita GDP, followed by quick recovery. Note, that if this is the case, we might see a negative effect on short-term GDP growth when looking at the impulse-response function, but no effect in the long-run, since the initial negative effect would be fully offset by the subsequent recovery. I argue that influenzas belong to this group. As I mentioned above, there is some evidence that the flu has a larger effect on countries and people at higher levels of income than other types of epidemics. In fact, as shown in Figure 6, when high income countries are left out and only developing countries are considered, the negative effect of influenzas is smaller and shorter-lived.

On the other hand, our theoretical model predicts that epidemics affecting unskilled workers generate higher growth both in the short-run and long-run (I argue that cholera epidemics belong to this group). There is no doubt that cholera affects primarily low and middle income countries, where the stock of human capital is very low, and cholera has stronger effects on unskilled workers.

Another question that we may ask is why the negative impact of influenzas occurs only with a one year or two year lag, rather than at the moment of the shock? The model presented above assumes the shock occurs suddenly and at a single point in time. However, actual epidemics do not occur in a single moment in time, but rather take time to spread and develop. A clear example is the current swine flu epidemic, which started at the beginning of 2009, but whose effects are expected to peak by January or February 2010. In my sample, the impact of the epidemic is taken at the moment when the outbreak begins, but many of these events last for more than a year. Hence, it is logical to expect that the decrease in GDP per capita could be observed in the second or third year of the event, which is what we see in the impulse-response functions.

A priori, Malaria and Arbovirus should also primarily affect the unskilled, but empirical evidence suggests that their impact differs from cholera. I don't have an explanation for these results and recognize them as a limitation of the model presented in section 3. However, as mentioned in the introduction, there are other models that predict a negative effect of epidemics on growth and may be cholera is the real puzzle. Also, the political economy explanation for cholera, which is outside of the model of section 2, is sensible and worthy of further study.

Conclusions

This paper contributes to the debate on the macroeconomic impact of epidemics by conducting a disaggregated analysis by type of epidemic. Specifically, the paper assesses the potentially different impacts of arbovirus, cholera, malaria and influenza on the short and long-run growth of per capita GDP.

My findings present strong evidence that the relationship between epidemics and growth depends on the type of epidemic. I show that a combined index of epidemics has a statistically insignificant association with overall GDP growth, which reflects the theoretical ambiguity and the inconsistent empirical evidence on the growth impact of epidemics in the received literature. I then attempt to disentangle this ambiguity by disaggregating the analysis by type of epidemic.

I find that the effect of cholera epidemics is strongly positive. Cholera could generate opportunities to implement health care reforms, such as investment in public health infrastructure which have the potential of improving long run growth performance. This country may use a cholera epidemic as an opportunity to obtain the political will, and perhaps the international aid, to reform and improve its health care infrastructure, which may in turn enhance economic growth in the short-run as a result of the increase in investment, and also in the long-run by increasing the incentives to invest in human capital.

By contrast, I find that the impact of arbovirus and influenza on growth is negative in the short-run but insignificant in the medium to long-run, which could be explained by the recovery generated in the years that follow the shock.

In light of this evidence, the paper argues that the current Swine Flu epidemic may exacerbate the economic damage already inflicted by the global recession.

However, the effects should be concentrated in the short-run, and we should see a quick recovery afterwards.

Table1

Growth and Epidemics

Dependent Variable: Five year average of growth rate of GDP pc

Sample: 94 countries, 1961-2005 (5-year period observations) *Estimation Method: Least Square*

VARIABLES	All	Arbovirus	Cholera	Malaria	Influenza
All Epidemics	0.007				
	[0.367]				
Epidemic X		-0.015	0.073***	0.025	-0.061
		[-0.446]	[2.820]	[0.569]	[-1.045]
Other Epidemics		0.010	-0.025	-0.000	0.014
		[0.490]	[-1.174]	[-0.0111]	[0.691]
Controls:					
Initial GDP	-0.522***	-0.524***	-0.406**	-0.508**	-0.510**
	[-2.591]	[-2.584]	[-1.989]	[-2.540]	[-2.495]
Education	0.648**	0.638**	0.516*	0.651**	0.610**
	[2.408]	[2.359]	[1.901]	[2.435]	[2.241]
Domestic Credit (% GDP)	0.256	0.260	0.244	0.256	0.246
	[1.267]	[1.283]	[1.214]	[1.272]	[1.215]
Government Spending (% GDP)	-1.842***	-1.871***	-1.887***	-1.830***	-1.906***
	[-4.688]	[-4.739]	[-4.829]	[-4.677]	[-4.808]
Inflation	-3.600***	-3.563***	-3.570***	-3.541***	-3.574***
	[-4.507]	[-4.425]	[-4.503]	[-4.426]	[-4.473]
Trade Openness	0.810***	0.831***	0.862***	0.784***	0.878***
	[3.139]	[3.188]	[3.353]	[3.070]	[3.331]
Growth of Terms of Trade	0.065***	0.065***	0.061***	0.065***	0.063***
	[3.437]	[3.435]	[3.254]	[3.435]	[3.363]
Dummy Area	Yes	Yes	Yes	Yes	Yes
Dummy Wars and Natural Disasters	Yes	Yes	Yes	Yes	Yes
Constant	23.899***	23.512***	24.208***	23.889***	22.762***
	[5.499]	[5.244]	[5.599]	[5.402]	[4.992]
Observations	544	544	544	544	544
Number of id	94	94	94	94	94

z-statistics in brackets

*** p<0.01, ** p<0.05, * p<0.1

Table 2

Growth and Epidemics

Dependent Variable: Five year average of growth rate of GDP pc

Sample: 94 countries, 1961-2005 (5-year period observations) *Estimation Method: System GMM*

VARIABLES	All	Arbovirus	Cholera	Malaria	Influenza
All Epidemics	0.004				
	[0.208]				
Epidemic X		-0.024	0.061***	0.003	-0.070
		[-0.794]	[3.010]	[0.0908]	[-1.419]
Other Epidemics		0.006	-0.017	0.002	0.007
		[0.349]	[-0.840]	[0.122]	[0.367]
Controls:					
Initial GDP	0.070	0.002	0.098	0.048	-0.015
	[0.138]	[0.00431]	[0.183]	[0.0939]	[-0.0287]
Education	0.809	0.730	1.083	0.739	0.715
	[1.175]	[1.048]	[1.616]	[1.071]	[1.040]
Domestic Credit (% GDP)	0.118	0.130	0.164	0.098	0.095
	[0.585]	[0.657]	[0.847]	[0.494]	[0.440]
Government Spending (% GDP)	-3.713***	-3.798***	-3.572***	-3.720***	-3.634***
	[-7.181]	[-7.075]	[-7.176]	[-6.639]	[-7.189]
Inflation	-5.818***	-5.611***	-5.263***	-5.894***	-5.474***
	[-5.302]	[-5.263]	[-5.083]	[-5.336]	[-5.013]
Trade Openness	1.197**	1.352**	1.384***	1.238**	1.337**
	[2.386]	[2.595]	[2.885]	[2.473]	[2.554]
Growth of Terms of Trade	0.055***	0.055***	0.053***	0.056***	0.052***
	[3.928]	[3.904]	[3.708]	[3.809]	[3.665]
Dummy Area	Yes	Yes	Yes	Yes	Yes
Dummy Wars and Natural Disasters	Yes	Yes	Yes	Yes	Yes
Constant	31.589***	30.799***	27.671***	32.381***	29.270***
	[4.295]	[4.289]	[3.830]	[4.400]	[4.047]
Observations	544	544	544	544	544
Number of id	94	94	94	94	94
Number of Instruments	55	55	55	55	55
AR(1)	0.000	0.000	0.000	0.000	0.000
AR(2)	0.400	0.374	0.265	0.394	0.374
Hansen	0.344	0.323	0.303	0.341	0.396

t-statistics in brackets

*** p<0.01, ** p<0.05, * p<0.1

Table 3

Growth and Epidemics

Dependent Variable: Five year average of growth rate of GDP pc

Sample: 94 countries, 1961-2005 (5-year period observations) *Estimation Method: System GMM*

Epidemics Treated as Endogenous Variable

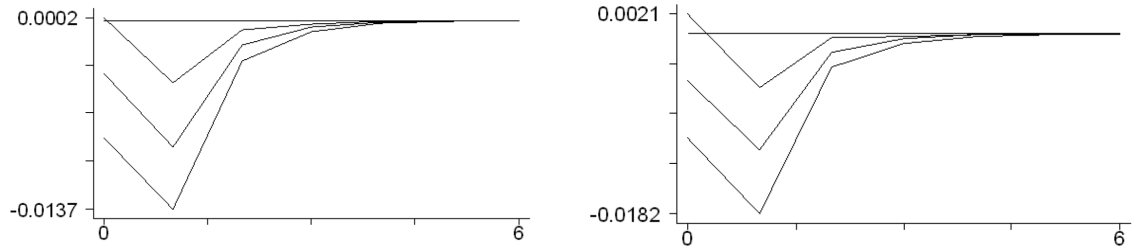
VARIABLES	All	Arbovirus	Cholera	Malaria	Influenza
All Epidemics	-0.013				
	[-0.348]				
Epidemic X		-0.050	0.110**	0.066	-0.294***
		[-1.141]	[2.543]	[1.431]	[-3.074]
Other Epidemics		0.004	-0.034	0.003	0.045*
		[0.169]	[-1.000]	[0.145]	[1.929]
Controls:					
Initial GDP	-0.226	-0.438	0.166	-0.086	-0.148
	[-0.510]	[-1.102]	[0.607]	[-0.201]	[-0.385]
Education	0.686	0.351	0.871*	0.460	0.855
	[1.117]	[0.613]	[1.678]	[0.713]	[1.420]
Domestic Credit (% GDP)	0.252	0.287	0.373**	0.095	0.141
	[1.287]	[1.577]	[2.017]	[0.490]	[0.677]
Government Spending (% GDP)	-4.103***	-3.210***	-3.971***	-2.968***	-3.123***
	[-8.337]	[-7.578]	[-8.312]	[-5.763]	[-6.278]
Inflation	-5.709***	-4.697***	-5.671***	-4.892***	-5.130***
	[-5.915]	[-5.403]	[-5.780]	[-4.883]	[-5.731]
Trade Openness	1.120**	1.331***	1.452***	1.287***	1.146**
	[2.317]	[2.779]	[3.089]	[2.677]	[2.450]
Growth of Terms of Trade	0.065***	0.067***	0.050***	0.059***	0.058***
	[5.648]	[6.370]	[4.179]	[4.886]	[4.591]
Dummy Area	Yes	Yes	Yes	Yes	Yes
Dummy Wars and Natural Disasters	Yes	Yes	Yes	Yes	Yes
Constant	34.553***	29.327***	29.872***	29.415***	23.991***
	[5.838]	[5.217]	[5.442]	[4.327]	[3.786]
Observations	544	544	544	544	544
Number of id	94	94	94	94	94
Number of Instruments	65	65	65	65	65
AR(1)	0.000	0.000	0.000	0.000	0.000
AR(2)	0.400	0.370	0.180	0.385	0.257
Hansen	0.415	0.161	0.504	0.218	0.733

t-statistics in brackets

*** p<0.01, ** p<0.05, * p<0.1

Figure 3: Response of Growth to an Arbovirus shock

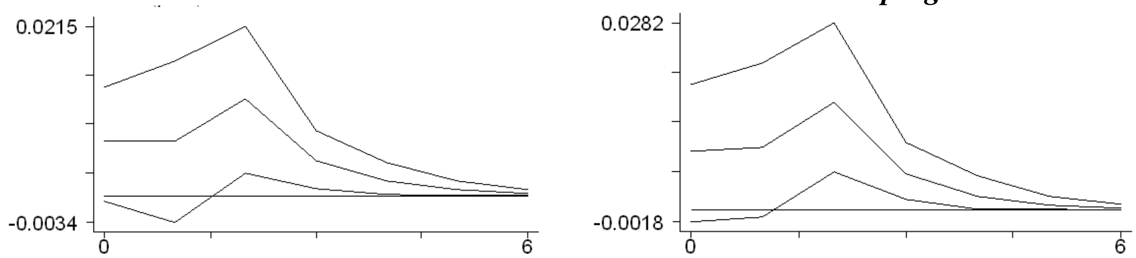
a. All Countries *b. Developing Countries*



Errors are 5% on each side generated by Monte-Carlo with 500 reps

Figure 4: Response of Growth to a Cholera shock

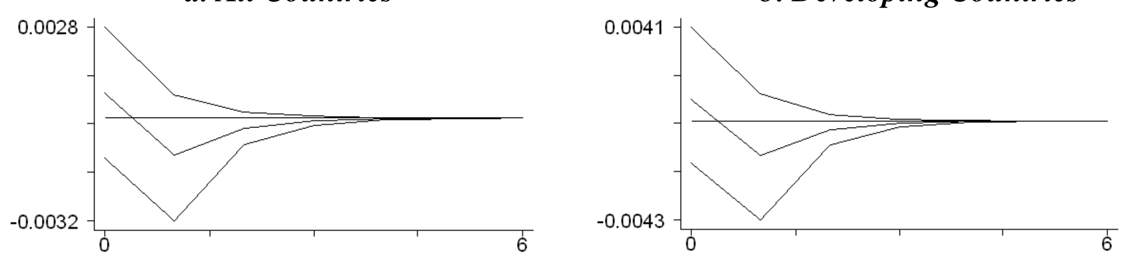
a. All Countries *b. Developing Countries*



Errors are 5% on each side generated by Monte-Carlo with 500 reps

Figure 5: Response of Growth to a Malaria shock

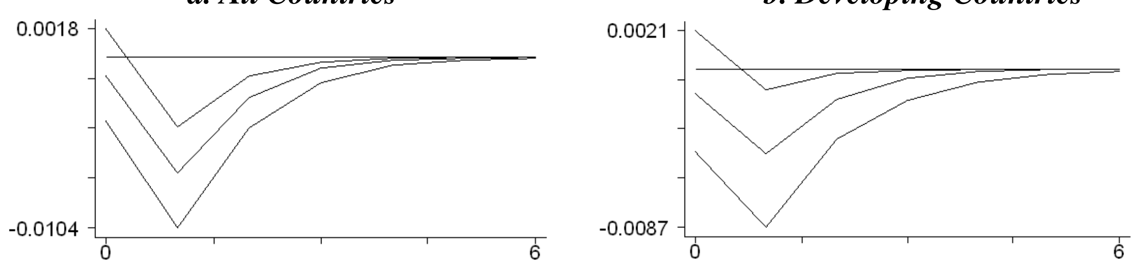
a. All Countries *b. Developing Countries*



Errors are 5% on each side generated by Monte-Carlo with 500 reps

Figure 6: Response of Growth to an Influenza shock

a. All Countries *b. Developing Countries*



Errors are 5% on each side generated by Monte-Carlo with 500 reps

Table A1
Descriptive Statistics
Sample: 94 countries, 1961-2005 (5-year period observations)

Variable	Obs	Mean	Std. Dev.	Min	Max
Growth rate GDP pc (%)	544	1.58	2.52	-5.75	9.86
Initial GDP pc (in logs)	544	7.62	1.56	4.44	10.53
Education: Enrollment in Secondary School (in logs	544	3.63	0.90	0.11	4.97
Financial Depth (in logs)	544	3.42	0.87	0.14	5.40
Government Burden (in logs)	544	2.62	0.37	1.42	3.36
Inflation (Log(100%+Growth Rate CPI))	544	4.71	0.14	4.57	5.78
Trade Openness (in logs)	544	4.00	0.58	2.21	6.00
Growth rate Terms of Trade (%)	544	-0.37	4.75	-18.86	21.42
All Epidemics (intensity in logs)	544	-8.31	9.45	-20.00	0.28
Arbovirus (intensity in logs)	544	-17.24	5.68	-20.00	0.01
Cholera (intensity in logs)	544	-10.84	7.30	-20.00	0.02
Malaria (intensity in logs)	544	-12.45	3.28	-20.00	0.28
Influenza (intensity in logs)	544	-16.97	4.42	-20.00	0.02

Chapter 4: Final Remarks and Policy recommendations

In his remarks to president Bush on August 17, 2006, US Treasury Secretary, Henry Paulson Jr, made clear that governments care a lot about the macroeconomic implications of rare events, such as natural disasters and epidemics, stating "We need to be prepare to deal with everything from ***natural disasters*** to oil price shocks, the collapse of a major bank, or a sharp drop in the value of the dollar."[24] The fact that the government assigns the same level of concern to natural disasters, as it does to oil price shocks, banking and currency crisis suggests that researching these events is important. However, most of the time policy makers concentrate only on the direct and inmediate damage generated by disaster events, and not on their long-run implications. This dissertation showed that medium-run and long-run implications are also important. A major conclusion of this dissertation is that rare events do matter for economic development and growth, and that governments should concentrate not only on policies that can reduce the initial disaster damage, but also on policies that can reduce the longer-term economic damage that disasters generate.

Long-term risks emanating from these rare events need to be better recognized, as their potential costs are a threat to economic development. The papers in this thesis demonstrate that some of these large events significantly reduce growth. Therefore, governments need appropriate risk management strategies for future

[24] Henry M. Paulson, Jr,, "On the Brink. Inside the Race to Stop the Collapse of the Global Financial System". Business Plus (2010) pp. 45

events, including medium-term financial planning covering 5 to 10 years. For example, natural hazard risk management should be integrated into longer-term national investment policies and development strategies and appropriately reflected in the allocation of financial resources.

The financial effects of disasters can have long-term implications for broader economic policy. In Dominica these severe budgetary effects have been a factor in the adoption of major reforms. In the aftermath of Hurricane David, Dominica undertook certain reforms under a program supported by the International Monetary Fund (IMF).

A second important conclusion is that, although rare events significantly affect economic development, their effects are not always negative and depend on the type of event being considered. Hence, in order to understand and assess the economic consequences of natural disasters and epidemics and the implications for policy, it is necessary to consider the pathways through which different types of events affect economic development, the different risks posed, and the ways in which economies can respond to these threats.

These differences partly relate to differences in the probability of occurrence. In some countries, droughts, floods, storms and cholera occur frequently, and it is economically worthwhile to adapt productive activities—for instance, agricultural practices—so as to reduce risk. It is also worthwhile to take appropriate structural and related measures pertaining to the design and location of buildings and other infrastructure. By contrast, options for reducing vulnerability to earthquakes are largely restricted to physical structural and locational factors.

In particular, our study shows that droughts have severe negative impacts on agriculture, and through that on economic development. This results should generate a concern. Governemnts need to strengthen climatic forecasting and promote the use of the information to support food security and improved management of agricultural and other renewable natural resources throughout the region. Climatic forecasting and information could help improve resilience to longer-term global climatic change by providing information that could be used to inform private and public decisions on the management of water resources, the choice of crops, and the level of grain exports and imports. Recognition of the severity of the economic impacts of drought should heighten the government's interest in structural adjustment programs and increase much needed investment to prevent and mitigate the consequences of disasters.

Cost-benefit analysis and investment analysis must be used to determine the economic efficiency of each type of disaster risk reduction action. Governments ought to develop a formal economic planning tool to assess risks more broadly by quantifying their potential implications for economic growth and the requirements for disaster prevention, mitigating their consequences and reconstruction funding. I believe that the findings of this thesis could act as a wakeup call to governments and the international community to take further preventive action. Papers of this kind can facilitate exploration of the implications of different types of rare event and the public choices concerning reconstruction financing and financial planning for them.

Appendices

More details on System GMM

The content of this appendix comes from Loayza et al (2009). After accounting for time-specific effects, we can rewrite the growth regression equation as:

$$y_{i,t} = \alpha\, y_{i,t-1} + \vec{\beta}' X_{i,t} + \eta_i + \varepsilon_{i,t} \qquad \text{(A.2)}$$

To eliminate the country-specific effect, we take first differences of equation A.2:

$$y_{i,t} - y_{i,t-1} = \alpha\left(y_{i,t-1} - y_{i,t-2}\right) + \beta'\left(X_{i,t} - X_{i,t-1}\right) + \left(\varepsilon_{i,t} - \varepsilon_{i,t-1}\right) \qquad \text{(A.3)}$$

The use of instruments is required to deal with the likely endogeneity of the explanatory variables and the problem that, by construction, the new error term, $\varepsilon_{i,t} - \varepsilon_{i,t-1}$, is correlated with the lagged dependent variable, $y_{i,t-1} - y_{i,t-2}$. The instruments take advantage of the panel nature of the data set in that they consist of previous observations of the explanatory and lagged-dependent variables. Conceptually, this assumes that shocks to economic growth (that is, the regression error term) be unpredictable given past values of the explanatory variables. The method does allow, however, for current and future values of the explanatory variables to be affected by growth shocks. It is this type of endogeneity that the method is devised to handle.

Under the assumptions that the error term, ε, is not serially correlated and that the explanatory variables are weakly exogenous (that is, the explanatory variables are assumed to be uncorrelated with future realizations of the error term), our application of the GMM dynamic panel estimator uses the following moment conditions:

$$E\left[y_{i,t-2} \cdot \left(\varepsilon_{i,t} - \varepsilon_{i,t-1} \right) \right] = 0 \qquad \text{(A.4)}$$

$$E\left[X_{i,t-2} \cdot \left(\varepsilon_{i,t} - \varepsilon_{i,t-1} \right) \right] = 0 \qquad \text{(A.5)}$$

for $t = 3,\ldots, T$.[25] (ee limit the set of instruments to five lags only, while the set of possible moment conditions includes all available lags. We do it to avoid overfitting bias. We return to this issue below.) As mentioned above, the indicator of epidemics and the measures of external shocks (in terms of trade, foreign growth, and capital flows) are treated as exogenous variables.

The GMM estimator based on the conditions in A.4 and A.5 is known as the difference estimator. Notwithstanding its advantages with respect to simpler panel data estimators, the difference estimator has important statistical shortcomings. Blundell and Bond (1998) and Alonso-Borrego and Arellano (1999) show that when the explanatory variables are persistent over time, lagged levels of these variables are weak instruments for the regression equation in differences. Instrument weakness influences the asymptotic and small-sample performance of the difference estimator toward inefficient and biased coefficient estimates, respectively.[26]

To reduce the potential biases and imprecision associated with the difference estimator, we use an estimator that combines the regression equation in differences and the regression equation in levels into one system (developed in Arellano and

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[25] Specifically, regarding the difference regression corresponding to the periods *t* and *t-1*, we use the following instruments: for the variables measured as period averages --financial depth, government spending, inflation, and trade openness-- the instrument corresponds to the average of period *t-2;* for the variables measured as initial values --per capita output and secondary school enrollment-- the instrument corresponds to the observation at the start of period *t-1*.

[26] An additional problem with the simple difference estimator involves measurement error: differencing may exacerbate the bias stemming from errors in variables by decreasing the signal-to-noise ratio (see Griliches and Hausman, 1986).

Bover, 1995, and Blundell and Bond, 1998). For the equation in differences, the instruments are those presented above. For the equation in levels (equation A.2), the instruments are given by the lagged differences of the explanatory variables.[27] These are appropriate instruments under the assumption that the correlation between the explanatory variables and the country-specific effect is the same for all time periods. That is,

$$\begin{aligned} &E[y_{i,t+p} \cdot \eta_i] = E[y_{i,t+q} \cdot \eta_i] \quad \textit{and} \\ &E[X_{i,t+p} \cdot \eta_i] = E[X_{i,t+q} \cdot \eta_i] \quad \textit{for all } p \textit{ and } q \end{aligned} \qquad \text{(A.6)}$$

Using this stationarity property and the assumption of exogeneity of future growth shocks, the moment conditions for the second part of the system (the regression in levels) are given by:

$$E[(y_{i,t-1} - y_{i,t-2}) \cdot (\eta_i + \varepsilon_{i,t})] = 0 \qquad \text{(A.7)}$$

$$E[(X_{i,t-1} - X_{i,t-2}) \cdot (\eta_i + \varepsilon_{i,t})] = 0 \qquad \text{(A.8)}$$

We thus use the moment conditions presented in equations A.2, A.5, A.7, and A.8 and employ a GMM procedure to generate consistent and efficient estimates of the parameters of interest and their asymptotic variance-covariance (Arellano and Bond 1991; Arellano and Bover 1995). These are given by the following formulas:

$$\hat{\theta} = (\overline{X}' Z \hat{\Omega}^{-1} Z' \overline{X})^{-1} \overline{X}' Z \hat{\Omega}^{-1} Z' \overline{y} \qquad \text{(A.9)}$$

$$AVAR(\hat{\theta}) = (\overline{X}' Z \hat{\Omega}^{-1} Z' \overline{X})^{-1} \qquad \text{(A.10)}$$

[27] The timing of the instruments is analogous to that used for the difference regression: for the variables measured as period averages, the instruments correspond to the difference between *t-1* and *t-2*; and for the variables measured at the start of the period, the instruments correspond to the difference between *t* and *t-1*.

where θ is the vector of parameters of interest (α, β); $\bar{\mathbf{y}}$ is the dependent variable stacked first in differences and then in levels; $\bar{\mathbf{X}}$ is the explanatory-variable matrix including the lagged dependent variable (y_{t-1}, X) stacked first in differences and then in levels; Z is the matrix of instruments derived from the moment conditions; and $\hat{\Omega}$ is a consistent estimate of the variance-covariance matrix of the moment conditions.[28]

Note that we use only a limited set of moment conditions. In theory the potential set of instruments spans all sufficiently lagged observations and, thus, grows with the number of time periods, *T*. However, when the sample size in the cross-sectional dimension is limited, it is recommended to use a smaller set of moment conditions in order to avoid over-fitting bias (see Arellano and Bond 1998; for a detailed discussion of over-fitting bias in the context of panel-data GMM estimation, see Roodman 2007). This is our case, and therefore we use two steps to limit the moment conditions. First, as described in detail above, we use as instruments only the *first appropriate lag* of each endogenous explanatory variable. Second, we use a common variance-covariance of moment conditions across periods. This results from substituting the assumption that the average (across periods) of moment conditions for a particular instrument be equal to zero for the assumption, conventional but more restrictive, that each of the period moment conditions be equal to zero.[29] At the cost of the reduced efficiency, our two steps decrease over-fitting bias in the presence of

[28] Arellano and Bond (1991) suggest the following two-step procedure to obtain consistent and efficient GMM estimates. First, assume that the residuals, $\varepsilon_{i,t}$, are independent and homoskedastic both across countries and over time; this assumption corresponds to a specific weighting matrix that is used to produce first-step coefficient estimates. Second, construct a consistent estimate of the variance-covariance matrix of the moment conditions with the residuals obtained in the first step, and then use this matrix to re-estimate the parameters of interest (that is, second-step estimates).
[29] This uses the "collapse" option of xtabond2 for STATA.

small samples by accommodating cases when the unrestricted variance-covariance is too large for estimation and inversion given both a large number of explanatory variables and the presence of several time-series periods.

The consistency of the GMM estimators depends on whether lagged values of the explanatory variables are valid instruments in the growth regression. We address this issue by considering two specification tests. The first is the Hansen test of overidentifying restrictions, which tests the validity of the instruments by analyzing the sample analog of the moment conditions used in the estimation process. Failure to reject the null hypothesis gives support to the model. The second test examines whether the original error term (that is, $\varepsilon_{i,t}$ in equation (A.2)) is serially correlated. The model is, therefore, supported when the null hypothesis is not rejected. In the system specification, we test in fact whether the first-differenced error term (that is, the residual of the equation in differences) is second-order serially correlated. First-order serial correlation of the differenced error term is expected even if the original error term (in levels) is uncorrelated, unless the latter follows a random walk. Second-order serial correlation of the differenced residual indicates that the original error term is serially correlated and follows a moving average process of at least order one.

Appendix 1
Descriptive Statistics
Sample: 94 countries, 1961-2005 (5-year period observations)

A) Economic Growth & Basic Determinants

Variable	Obs	Mean	Median	Std. Dev.	Min	Max
Growth GDP pc (%)	545	1.58	1.74	2.52	-5.75	9.86
Growth Agricultural Sector (%)	545	0.33	0.41	2.83	-13.17	11.49
Growth Industrial Sector (%)	545	1.73	1.62	3.84	-13.43	19.10
Growth Service Sector (%)	545	1.83	2.12	2.90	-13.14	12.33
Initial GDP pc (in logs)	545	7.61	7.48	1.55	4.44	10.53
Initial Agricultural Output pc (in logs)	545	5.25	5.26	0.79	2.87	7.97
Initial Industrial Output pc (in logs)	545	6.28	6.20	1.70	2.79	9.53
Initial Service Output pc (in logs)	545	6.92	6.82	1.69	3.22	10.09
Education (in logs)	545	3.62	3.80	0.90	0.11	4.97
Financial Depth (in logs)	545	3.42	3.38	0.87	0.14	5.40
Government Burden (in logs)	545	2.62	2.61	0.37	1.42	3.36
Inflation (log(100+%Growth rate of CPI))	545	4.71	4.67	0.14	4.57	5.78
Trade Openness (in logs)	545	4.00	4.01	0.58	2.21	6.00
Growth rate of Terms of Trade	545	-0.38	-0.36	4.74	-18.86	21.42

B) Natural Disasters: Unconditional summary statistics

Variable	Obs	Mean	Median	Std. Dev.	Min	Max
All Disasters (intensity in logs)	545	-9.81	-8.09	5.34	-20.00	-2.74
Droughts (intensity in logs)	545	-16.89	-20.00	5.84	-20.00	-2.74
Floods (intensity in logs)	545	-12.31	-10.09	5.73	-20.00	-3.52
Earthquakes (intensity in logs)	545	-17.19	-20.00	4.65	-20.00	-3.04
Storms (intensity in logs)	545	-15.66	-20.00	5.28	-20.00	-3.53
All Disasters (incidence: avg. num. of events)	545	0.47	0.20	0.66	0.00	5.40
Droughts (incidence: avg. num. of events)	545	0.06	0.00	0.14	0.00	0.80
Floods (incidence: avg. num. of events)	545	0.24	0.20	0.36	0.00	2.20
Earthquakes (incidence: avg. num. of events)	545	0.04	0.00	0.11	0.00	0.80
Storms (incidence: avg. num. of events)	545	0.12	0.00	0.37	0.00	3.40

C) Natural Disasters: Conditional on the occurrence of natural disasters

Variable	Obs	Mean	Median	Std. Dev.	Min	Max
All Disasters (intensity in logs)	454	-7.76	-7.33	3.03	-17.66	-2.74
Droughts (intensity in logs)	125	-6.45	-5.90	2.63	-16.43	-2.74
Floods (intensity in logs)	374	-8.79	-8.47	2.88	-19.09	-3.52
Earthquakes (intensity in logs)	163	-10.60	-10.22	3.23	-18.97	-3.04
Storms (intensity in logs)	254	-10.70	-10.39	3.67	-19.50	-3.53
All Disasters (incidence: avg. num. of events)	375	0.68	0.40	0.69	0.20	5.40
Droughts (incidence: avg. num. of events)	114	0.30	0.20	0.16	0.20	0.80
Floods (incidence: avg. num. of events)	284	0.47	0.40	0.38	0.20	2.20
Earthquakes (incidence: avg. num. of events)	88	0.25	0.20	0.13	0.20	0.80
Storms (incidence: avg. num. of events)	132	0.50	0.20	0.60	0.20	3.40

Appendix 2
Descriptive Statistics: Developing Countries
Sample: 68 developing countries, 1961-2005 (5-year period observations)

A) Economic Growth & Basic Determinants

Variable	Obs	Mean	Median	Std. Dev.	Min	Max
Growth GDP pc (%)	407	1.35	1.46	2.71	-5.75	8.49
Growth Agricultural Sector (%)	407	0.12	0.30	2.83	-13.17	8.76
Growth Industrial Sector (%)	407	1.68	1.68	4.19	-13.43	19.10
Growth Service Sector (%)	407	1.58	1.90	3.18	-13.14	12.33
Initial GDP pc (in logs)	407	6.92	6.92	1.12	4.44	10.14
Initial Agricultural Output pc (in logs)	407	4.95	4.98	0.60	2.87	6.20
Initial Industrial Output pc (in logs)	407	5.58	5.69	1.35	2.79	9.35
Initial Service Output pc (in logs)	407	6.17	6.18	1.24	3.22	9.94
Education (in logs)	407	3.32	3.47	0.84	0.11	4.73
Financial Depth (in logs)	407	3.15	3.16	0.78	0.14	5.27
Government Burden (in logs)	407	2.52	2.49	0.35	1.42	3.32
Inflation (log(100+%Growth rate of CPI))	407	4.73	4.69	0.16	4.57	5.78
Trade Openness (in logs)	407	4.00	3.99	0.60	2.21	6.00
Growth rate of Terms of Trade	407	-0.58	-0.61	5.27	-18.86	21.42

B) Natural Disasters: Unconditional summary statistics

Variable	Obs	Mean	Median	Std. Dev.	Min	Max
All Disasters (intensity in logs)	407	-8.76	-7.27	5.02	-20.00	-2.74
Droughts (intensity in logs)	407	-15.95	-20.00	6.37	-20.00	-2.74
Floods (intensity in logs)	407	-11.42	-8.95	5.77	-20.00	-3.52
Earthquakes (intensity in logs)	407	-17.09	-20.00	4.77	-20.00	-3.04
Storms (intensity in logs)	407	-15.55	-20.00	5.51	-20.00	-3.53
All Disasters (incidence: avg. num. of events)	407	0.57	0.40	0.72	0.00	5.40
Droughts (incidence: avg. num. of events)	407	0.08	0.00	0.16	0.00	0.80
Floods (incidence: avg. num. of events)	407	0.30	0.20	0.39	0.00	2.20
Earthquakes (incidence: avg. num. of events)	407	0.04	0.00	0.10	0.00	0.80
Storms (incidence: avg. num. of events)	407	0.14	0.00	0.41	0.00	3.40

C) Natural Disasters: Conditional on the occurrence of natural disasters

Variable	Obs	Mean	Median	Std. Dev.	Min	Max
All Disasters (intensity in logs)	354	-7.07	-6.76	2.67	-16.38	-2.74
Droughts (intensity in logs)	122	-6.48	-5.91	2.65	-16.43	-2.74
Floods (intensity in logs)	292	-8.03	-7.85	2.43	-16.38	-3.52
Earthquakes (intensity in logs)	122	-10.31	-9.91	3.16	-18.97	-3.04
Storms (intensity in logs)	181	-10.00	-9.65	3.56	-18.83	-3.53
All Disasters (incidence: avg. num. of events)	318	0.73	0.40	0.74	0.20	5.40
Droughts (incidence: avg. num. of events)	111	0.30	0.20	0.15	0.20	0.80
Floods (incidence: avg. num. of events)	252	0.49	0.40	0.40	0.20	2.20
Earthquakes (incidence: avg. num. of events)	71	0.25	0.20	0.11	0.20	0.80
Storms (incidence: avg. num. of events)	107	0.54	0.20	0.66	0.20	3.40

Table B1

Pair-Wise Correlation

Sample: 94 countries, 1961-2005 (5-year period observations)

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	Growth rate GDP pc (%)	1.00																							
2	Growth rate Agricultural GDP pc (%)	0.33	1.00																						
3	Growth rate Industrial GDP pc (%)	0.83	0.14	1.00																					
4	Growth rate Service GDP pc (%)	0.82	0.21	0.54	1.00																				
5	Initial GDP pc (in logs)	0.21	0.10	0.03	0.19	1.00																			
6	Initial Agricultural Value Added pc (in logs)	0.20	0.05	0.11	0.19	0.74	1.00																		
7	Initial Industrial Value Added pc (in logs)	0.22	0.11	0.01	0.20	0.98	0.71	1.00																	
8	Initial Service Value Added pc (in logs)	0.20	0.10	0.03	0.17	0.99	0.73	0.97	1.00																
9	All Disasters (intensity in logs)	-0.04	0.00	-0.03	-0.02	-0.29	-0.18	-0.26	-0.28	1.00															
10	Droughts (intensity in logs)	-0.16	-0.14	-0.09	-0.08	-0.34	-0.31	-0.34	-0.34	0.52	1.00														
11	Floods (intensity in logs)	0.08	0.11	0.03	0.07	-0.21	-0.11	-0.17	-0.20	0.73	0.24	1.00													
12	Earthquakes (intensity in logs)	0.02	0.03	-0.02	0.03	0.08	0.14	0.11	0.09	0.40	0.18	0.33	1.00												
13	Storms (intensity in logs)	0.07	0.03	0.01	0.09	0.08	0.09	0.07	0.10	0.47	0.24	0.27	0.26	1.00											
14	Education: Enrollment in Secondary School	0.24	0.15	0.02	0.23	0.79	0.60	0.81	0.78	-0.10	-0.22	-0.02	0.15	0.22	1.00										
15	Financial Depth (in logs)	0.26	0.06	0.10	0.24	0.73	0.51	0.72	0.74	-0.16	-0.19	-0.07	0.04	0.16	0.62	1.00									
16	Government Burden (in logs)	-0.06	0.02	-0.13	-0.04	0.40	0.23	0.39	0.38	-0.26	-0.12	-0.28	-0.18	-0.19	0.32	0.38	1.00								
17	Inflation (Log(100%+Growth Rate CPI))	-0.25	-0.06	-0.22	-0.19	-0.08	-0.08	-0.05	-0.08	0.16	0.13	0.17	0.15	-0.06	-0.01	-0.24	-0.20	1.00							
18	Trade Openness (in logs)	0.09	-0.03	0.07	0.05	0.15	-0.02	0.17	0.15	-0.21	-0.13	-0.23	-0.26	-0.14	0.22	0.24	0.34	-0.28	1.00						
19	Growth rate Terms of Trade (%)	0.15	0.13	0.05	0.19	0.11	0.07	0.13	0.09	-0.07	-0.03	-0.05	0.01	-0.03	0.08	0.06	0.05	-0.08	0.06	1.00					
20	All Epidemics (intensity in logs)	-0.06	-0.12	0.00	-0.02	-0.05	-0.01	-0.07	-0.05	0.08	0.12	-0.09	-0.03	0.00	-0.03	0.02	0.00	0.04	-0.07	0.04	1.00				
21	Arbovirus (intensity in logs)	-0.01	-0.04	0.01	0.00	-0.10	-0.09	-0.08	-0.09	0.15	0.20	0.21	0.18	0.12	0.02	0.01	-0.23	0.15	-0.03	0.02	-0.05	1.00			
22	Cholera (intensity in logs)	0.01	0.04	-0.02	0.04	-0.28	-0.24	-0.26	-0.35	0.18	0.26	0.22	0.07	0.03	-0.15	-0.22	-0.17	0.06	-0.11	0.04	0.02	0.33	1.00		
23	Malaria (intensity in logs)	0.04	0.06	0.03	0.06	-0.15	-0.14	-0.14	-0.16	0.15	0.20	0.14	0.11	0.04	-0.03	-0.06	-0.05	-0.01	-0.07	-0.02	0.36	0.18	0.30	1.00	
24	Influenza (intensity in logs)	0.05	-0.01	-0.02	0.03	0.10	0.00	0.10	0.10	0.07	0.07	0.09	0.09	0.17	0.14	0.17	-0.03	-0.09	0.13	0.03	-0.05	0.02	-0.03	0.01	1.00

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