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Essays on Environmental Shocks and Economic Development

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PhD Thesis

March 20, 2013

Declaration

I hereby declare that this thesis has not been submitted previously as an exercise for a degree at this or any other University. The research presented in this thesis is entirely my own work, except where otherwise explicitly acknowledged in the text. Chapters 2 and 5 are based on research carried out in collaboration with my supervisor Frank Barry, and also with Richard Tol, who acted as an informal co-advisor throughout my PhD studies. This research has previously been disseminated through working paper series at the ESRI and TCD. I agree that the library may lend or copy the thesis upon request. This permission covers only single copies made for study purposes, subject to normal conditions of acknowledgement.

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Of course the usual disclaimer applies and all remaining errors, omissions, mistakes and mis-steps are the responsibility of the author alone.

Dedication

To Woody, whose walks helped keep me sane, for being a great listener.

Summary

This thesis investigates the effects of environmental shocks, in the form of natural disasters and rainfall volatility, on economic development. I pursue both theoretical and empirical investigations of these issues. In Chapters 2 and 3, I present theoretical analyses of the impacts of disaster shocks on investment in physical and human capital, respectively. I show that the investment response to disasters depends on access to credit, and that where access to credit is problematic, investment will not fully compensate for the destruction of assets due to the disaster event.

I also conduct empirical analysis of the effects of disasters for economic growth and for education and health outcomes, at a macro level, i.e. using country-level data. My analysis is based on a panel of data that covers 170 countries, for the period 1979-2007 and includes data on thousands of disaster events. I find, in contrast to some of the existing literature on the economics of natural disasters, that disasters can have persistent as opposed to transient impacts on economic growth. The persistence of the growth effects depends on the availability of credit in the affected region. The magnitude of the results is also economically meaningful; a disaster that occurs in a country with relatively weak financial sector development can completely wipe out economic growth for up to three years after the event, while the impact on growth rates will remain significant for up to 10 years.

In the case of human capital impacts, I show in Chapter 3 that disasters reduce life expectancy and school enrollment rates and raise mortality rates for mothers, infants and under-5's. While it is not surprising that disasters have profound

impacts on human welfare, my results presented in Chapter 3 show again that these impacts are not transitory in nature, but rather persist and are detectable in the data at up to 15 years after the disaster event. In general, and unsurprisingly, the magnitude of the effects is greater for poor countries, who are less likely to be able to cope with the effects of disasters, due to institutional and economic factors. My results also show that disasters appear to have a stronger effect on life expectancy for females than for males, suggesting a gender-based aspect to the impacts. For the health impacts identified, I show that income - including foreign aid - can be effective in mitigating the effects of disasters. However, in the case of school enrollment, access to credit appears to matter more.

In Chapters 4 and 5 I turn my attention to the relationship between environmental volatility and long-term (comparative) economic development. In Chapter 4 I replicate the analysis from a well known study on the role of geography and institutions in the 'origins' of comparative economic development. Using a sophisticated empirical strategy - including finite mixture model regressions and Monte Carlo simulations - I show that ignoring the bi-modality of global income may have caused previous authors mistakenly to have discounted the role of geographic factors in comparative economic development.

In Chapter 5 I build on the findings of the previous chapter and investigate the role of rainfall volatility - a geographic variable with a more plausible causative relationship to income than the standard proxies used in previous literature, such as latitude - in the process of long-term economic development. This chapter uses an existing model of economic development as its theoretical basis. The model gives a central role to luck or chance events in the process of economic development. I test empirically the implications of the model, by positing rainfall volatility as the source of economic 'luck'. My analysis - again using a finite mixture model approach - shows that poorer countries are vulnerable to environmental volatility, which appears to delay their takeoff to modern economic growth. In particular, hot, landlocked countries with unpredictable (i.e. volatile) rainfall are more likely to be stuck in the poor regime. I also find that geographic variables are better at explaining income for relatively poor countries, while institutions and socio-cultural variables appear to be better predictors of income across relatively rich

countries.

The final chapter of the thesis (Chapter 6) concludes with a discussion of the main findings and their implications both for development policy and for academic studies related to the issues I have addressed in the thesis. I also propose some ideas for future research projects that might profit from the insights and findings of this thesis.

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Chapter 1

Introduction

1.1 General introduction of the research topic

A string of recent high profile events has given us a vivid reminder of Nature's destructive capacity. Disasters are, by definition, costly events. According to the World Bank, 2.6 billion people have been affected by natural disasters over the past decade, while estimates of the economic losses associated with individual events can run into the hundreds of billions of US dollars (Thomas, 2011).

In spite of the vast scale of these effects, mainstream academic economics has had relatively little to say on the potential for natural disasters to affect the prospects for economic development in affected regions. In part this reflects the predominant economic paradigm. Standard workhorse models of economic growth depict economies converging over time to their 'steady-state' growth paths (Lecocq & Shalizi, 2007). In this context, shocks of various kinds merely represent transient disturbances, with minimal lasting influence on the trajectory of the economy. Reflecting such a viewpoint, Albala-Bertrand (1993, p.4) characterises the economy as "an ever-active system of institutions and in-built behaviours hardly hampered by setbacks and interferences like disasters". While such re-

silience to shocks may be a reasonable characterisation of rich, developed world economies, poorer countries may lack the economic flexibility - the necessary 'shock absorbers' - to prevent the occurrence of a natural disaster from derailing economic growth (Loayza *et al.* , 2007).

The relegation of natural disasters to a position of relative insignificance within the macroeconomic literature also reflects a general tendency, until relatively recently, to discount the role of geographic and environmental factors in economic development. However, there has been a resurgence of interest in this area in recent years (e.g. Sachs *et al.* , 2001). This work has been motivated, in part, by dissatisfaction with traditional growth models that have proven to be inadequate in attempting to explain the diverse long-run growth experiences across different regions of the world economy. Renewed interest in geographic and environmental factors and their relationship with the economy has also stemmed from concerns over the potential for future climate change to affect the prospects for economic development, particularly in poorer countries.

An additional factor in the relative neglect of geography - broadly defined - in explanations of economic development, has been the tendency to treat all countries as equals in cross-country comparisons. In reality, the evolving nature of economic vulnerability likely implies distinct relationships between environmental factors and economic growth for countries at different stages of economic development, a notion which this thesis takes seriously. In my analysis, I take explicit account of the dynamic interaction between environmental factors and the evolution of socio-economic development. Vulnerability to environmental shocks and volatility is dependent on the level of socio-economic development of the affected region, as discussed in detail in Section 1.2.2 below.

While traditional theories of economic growth have tended to discount the role of shocks, there is a growing appreciation in the literature of the potential importance of macroeconomic volatility in determining the prospects for long-run growth. Robert Solow, whose contributions to growth theory over 50 years ago have formed the basis for much of the work that has followed in this area, has recently argued for greater effort to be expended in attempting to reconcile the traditional dichotomy between the economics of the short and long run (Solow,

2005).

There is also an increasing awareness among macroeconomists of the need to take account of the possibility of extreme (i.e. rare or unlikely but large) events. This point is made by Cavallo & Noy (2009) and, in the context of the recent financial crisis, by Krugman.¹ Hnatkovska & Loayza (2005) show that it is not the volatility due to ‘normal fluctuations’, but rather the volatility due to crises, that harms economic growth over the long run. A recent World Bank Note has also called for more explicit consideration of natural disaster risks in macroeconomic scenarios (Thomas, 2011). The *rare disasters hypothesis* (see e.g. Barro, 2006; Gabaix, 2008) suggests that taking account of rare economic ‘disasters’ - i.e. large drops in output per capita - can help solve a number of puzzles in financial macroeconomics, such as the equity premium puzzle. In the context of climate change impacts, the need to take account of the probability distribution of events, rather than simply the mean or most likely event scenario, has been highlighted by a number of authors (e.g. Hallegatte *et al.* , 2007; Hendry, 2010; Weitzman, 2007, 2009).

In this thesis I investigate the role of environmental extremes in the process of economic development. Specifically, I examine the effects of natural disaster shocks on economic growth and on the accumulation of human capital over the medium-term. I also test the more general long-term relationship between environmental volatility and economic development. The two types of environmental volatility included in my analysis - disaster shocks on the one hand and a more chronic exposure to environmental volatility (e.g. in the form of unpredictable rainfall) on the other - require somewhat distinct approaches.

This distinction is reflected in the theoretical framework used. For disasters, I use a two-period framework, which allows for before-and-after comparisons of the economic effects of disasters. My analysis is aimed at developing a better understanding of the circumstances under which disasters may have persistent as opposed to transitory effects for economic development. The empirical approach that I use also reflects the emphasis on the economic dynamics in response to a

¹Paul Krugman, “How did economists get it so wrong?” New York Times Magazine, February 9, 2009.

disaster shock. I make use of panel data in order to test directly the medium-term effects of disasters on economic growth and on the accumulation of human capital.

In the case of environmental volatility, the relevant relationship is the long-run equilibrium between environment and development. The theoretical framework used to analyse this relationship is based on Acemoglu & Zilibotti's (1997) model of development, which illustrates the long-term, cumulative effects of 'bad luck', in the form of random shocks, for economic development. I posit environmental volatility as the source of this 'bad luck', and test the theory using a sophisticated empirical strategy, which explicitly accounts for the potentially diverse effects of environmental factors across rich and poor countries.

1.1.1 Contribution

This thesis contributes to the existing literature in a number of important ways. In relation to disasters, the short-term, direct effects are quite obvious and have been documented elsewhere. However, the results presented here are among the first to demonstrate the effects of disasters on human capital at a macroeconomic level. More significantly, I also demonstrate that - under specific circumstances - disasters can have persistent effects on both economic growth and on the accumulation of human capital, over the medium-term. As mentioned, traditional theories of economic growth would suggest that the effects of disasters are negligible from an economic point of view over the medium to long-term, as the economy is expected to recover quite rapidly from shocks or disturbances. In my analysis, I demonstrate that once we take account of some of the constraints to recovery faced by relatively poor countries - in particular in relation to the availability of credit - the effects of disasters are likely to be persistent over the medium-term. I also propose and test a specific mechanism for the transmission of short-term shocks due to disasters to the performance of output over the medium-term.

As far as I am aware, this thesis represents the first attempt to quantify the medium-term impacts of natural disasters, and to identify the circumstances under which such events have persistent, as opposed to transitory, effects on

economic output and on health and education outcomes at a macro level.

Turning to the long-term relationship between environmental factors and economic development, I contribute to the literature in this area by addressing two specific weaknesses in the existing literature. First, and most importantly, I use a sophisticated empirical strategy that allows for the separate identification of effects across rich and poor countries. This allows me explicitly to account for the idea that not all countries are alike - more specifically, that there are distinct growth regimes across rich and poor countries. I also demonstrate how ignoring this distinction could have biased the results of previous studies, resulting in somewhat misleading conclusions on the role of geography-based variables in explaining comparative levels of economic development.

A further contribution to this literature is the use of a novel explanatory variable, in the form of rainfall volatility. Unlike some of the proxies for geography used in the existing literature (e.g. latitude), this variable has a plausible causal relationship with income.

Although volatile rainfall may not appear as dramatic as the occurrence of a natural disaster, its economic effects may be no less pernicious. Of course, extremes of rainfall - either prolonged absence or excessive abundance over a short period - can trigger disasters. However, it is the economic behaviour of households in response to an unpredictable environment, which is likely to have the most profound effects for economic development over the long-term.

The results contained in this thesis will be of relevance to academics and policy-makers alike. In the conclusions of each chapter, I discuss the implications of my findings - in particular, with regard to development policies. In general, a better understanding of how environmental factors (including disasters and climate) interact with economic development could provide useful inputs into the assessment of climate change risk. Chapter 5 also includes a reconceptualisation of the notion of economic ‘takeoff’.

1.1.2 Research model and methodology

The decision to take a macroeconomic perspective in my analysis is motivated first of all by my own background and interest, which has been for some time, macroeconomic approaches to issues of economic growth and development. The chosen approach is further justified on the basis of gaps that I have identified in the existing literature. An alternative methodology for this research would be a case study approach. However, such an approach would present significant logistical challenges, while not necessarily representing a good ‘methodological fit’ with my stated research question(s). Following the logic of the hypothetico-deductive research model, my research comprises two main elements: theoretical and empirical. Emerging from the literature review and my theoretical work, are a number of clear hypotheses, which I test empirically against available data. It is essential that any econometric analysis is built on solid theoretical foundations (e.g. to inform decisions about what functional form might be appropriate and choices regarding what variables to include).

The theoretical modelling approach that I employ follows the standard optimization techniques that are common in theoretical economic work, and that have their origins in Ramsey (1928). Such models make a number of important assumptions about the behaviour of economic agents. In particular, it is assumed that agents are ‘rational optimizers’ in that they seek to maximize lifetime welfare, subject to a given set of constraints regarding lifetime income. While such assumptions may not represent the ‘truth’ with regard to human behaviour, they nonetheless provide a useful idealised (and thus much simplified) benchmark against which to compare our observations about actual behaviour.

While every effort has been made to ensure that the empirical results presented here are reliable, results from studies of this nature must always be interpreted with caution and potential threats to the validity of the findings assessed. Results are to be interpreted only in the context of the implicit *ceteris paribus* condition. Any generalizations or claims regarding causality should be based firmly in economic theory, while all results, to the extent that they are statistically significant and robust to various checks, only represent ‘knowledge claims’ that may be falsified in future research. This last point highlights the importance of transparency

with regard to assumptions, methods and data used in the research.

1.2 Definitions

1.2.1 Defining ‘natural disasters’

“Only when these natural phenomena cause damage to man and his artifacts can they properly be called *disasters*.” - Dacy & Kunreuther (1969, p.3, italics in the original)

So-called ‘natural’ disasters are defined by their impacts on the human population. For example, the International Disaster Database (EM-DAT) applies the following criteria for the inclusion of a disaster event: ten (10) or more people reported killed; a hundred (100) or more people reported affected; a declaration of a state of emergency; or a call for international assistance. Thus natural disasters, far from representing purely random acts of God or Nature, are inherently socially-defined phenomena (see Sen, 1983).

Natural disasters are generally triggered by some naturally occurring geophysical or meteorological event. However, the measurable effects of disasters (in terms of the numbers of people killed or injured or the associated economic losses) are a result of the interaction between the trigger event and the socio-economic system. The impacts of disaster events therefore depend very much on context, and on the socio-economic circumstances prevailing at the specific time and location of the event occurrence.²

It is no surprise then that disasters affect poorer countries, poorer regions within countries, and the poorest strata of society disproportionately.³ A widely quoted figure from the World Bank estimates that 97% of natural disaster related deaths occur in developing countries, while economic losses as a proportion of GNP in poor countries far exceed those in the rich world (WB, 2000). Perhaps

²This point is made in Tol & Leek (1999).

³For evidence of this, see for example, Albala-Bertrand (1993); Kellenberg & Mobarak (2008).

this explains the persistence in various reports by government and international agencies, NGOs etc., of the perception that natural disasters represent a significant barrier to economic development (e.g. UN, 2002; Thomas, 2011). And yet, until relatively recently, this view has not been reflected in the academic economic literature. On the contrary, disaster events have generally been treated as unimportant, from a macroeconomic perspective.

1.2.2 Poverty and vulnerability

Poor countries face a more hostile environment - i.e. they are on average hotter, with more volatile rainfall, and a greater exposure to various kinds of natural hazards - than their rich counterparts, and also suffer more severe effects from natural disaster events. In this section I explore the links between poverty and economic vulnerability, drawing some tentative conclusions on the channels through which a capricious natural environment could potentially cause long-term economic damage.

Poor countries (and poorer people) are likely to be inherently more vulnerable to the effects of extreme events for a number of reasons; for example, because of geography and human settlement patterns in poor countries (UN, 2002), or because poor people tend to live on marginal lands and in relatively low standard accommodation (see Albala-Bertrand, 1993; Sen, 1983; Kellenberg & Mobarak, 2008). It is also the case that poor countries tend to be more heavily reliant on agricultural output - a sector which is particularly weather dependent. Poor countries may also struggle to cope with the effects of an extreme event due to institutional or political factors (Kahn, 2005).

Greater vulnerability will likely lead to more severe direct impacts of disasters. Extreme events, to the extent that they damage or destroy buildings and infrastructure and/or kill and injure people, clearly represent a negative shock, in both human and economic terms. Such negative shocks will always have welfare effects. However, it is not clear that such shocks will necessarily have economic *growth* effects.

As noted by Auffret (2003), under the general equilibrium framework (Debreu,

1959; Arrow & Hahn, 1971), with the assumption of complete markets, agents should be able to trade risk through financial and insurance markets, thereby avoiding turning production or income volatility into consumption and investment volatility. Thus shocks should have only transient effects on economic output - a theoretical result that has long consigned short-run shocks to a position of relative insignificance within the literature.⁴

While greater vulnerability tends to exacerbate the direct effects of extreme events, in relation to the specific types of vulnerability mentioned above, their expected consequences for the economic growth impacts of disasters are ambiguous *a priori*. If more people are killed or injured by an extreme event occurrence, the direct impact on the economy is to reduce the available labour force, thus presumably leading to a short-term fall in output. However, it is not generally thought that changes in the absolute size of the labour force (or population) tend to affect the rate of economic growth.⁵

If more is destroyed by a disaster (as a fraction of the capital stock, or as a percentage of GDP) this obviously reduces the available productive resources in the economy and therefore is likely to lead to a fall in output in the short-term. However, such impacts are not necessarily bad for growth prospects. We would expect that any reduction in the capital stock would be compensated for by increased investment.⁶ In fact, such effects in theory could be beneficial for economic growth. Reconstruction efforts may represent an old fashioned Keynesian type stimulus (where the economy is not operating at full capacity) thus boosting economic growth. Similarly, the destruction of capital may represent an opportunity to replace what was destroyed with better technology or to upgrade

⁴In a celebrated series of lectures, Robert Lucas argued that business cycle fluctuations were relatively unimportant for welfare (Lucas, 1987).

⁵This relationship may become more complex, and interesting, if it is the case that extreme events affect certain age-groups disproportionately, thus impacting on the demographic profile of the population - something which has been shown to influence economic growth (see Bloom *et al.*, 2001).

⁶The prevailing rate of interest in the economy determines the required rate of return on investments, or in other words the necessary marginal product of capital required to attract investment. This pins down the capital-labour ratio in equilibrium. Thus a shock that destroys relatively more capital than labour will stimulate investment as the marginal product of capital rises in response to the fall in the capital stock. This logic of course assumes diminishing marginal returns to capital.

infrastructure. In this case the shock of the capital destruction may represent a Schumpeterian ‘creative destruction’ impulse to economic growth.

It is possible that an extreme event occurrence may cause permanent (or at least long-term) damage to the productivity of the agricultural sector, with obvious consequences for the growth prospects of relatively poor countries that are highly dependent on agricultural output. For example, Hornbeck (2009) has shown that the effects of the American Dust Bowl in the 1930s on agricultural output and land values in the affected regions, were persistent over several decades, while adjustment to the shock occurred mostly through mass out-migration and economic decline (as opposed to a shift to non-agricultural economic activity). Clearly such a scenario could explain, at least partially, the more severe growth effects of extreme events in poor countries. However, at least one study (Dell *et al.*, 2008) has shown that their findings in relation to poor countries are not simply a result of ‘poor’ being a proxy for dependency on agriculture. It seems there must be ‘something else’, as Easterly & Levine (2001) might put it, that causes transient shocks to have persistent effects in poor countries.⁷

By definition the poor lack own-resources, and are thus less able to cope with the effects of various types of shocks.⁸ In a world of complete and competitive markets, we would not expect a lack of own-resources to constrain investment decisions. However, reality rarely corresponds to such a world. It has been shown that the poor often lack access to credit, due to market imperfections and consequent collateral requirements for loans (see for example the review of literature on finance and inequality by Demirguc-Kunt and Levine, 2009). Thus,

⁷Either there is ‘something else’ not accounted for by the vulnerability factors discussed here, or it may be that the interaction of vulnerability and extreme events is more complex than generally has been appreciated in the macroeconomic literature to date. One potentially important channel of effect is through the political economy impacts of disasters. However, such effects appear to be well covered in the existing literature (see for example Kellenberg & Mobarak, 2008; Anbarci *et al.*, 2005; Kahn, 2005). I choose not to study such effects in detail, preferring instead to focus on more purely macroeconomic factors. In particular, my research focusses on the investment effects of extreme events. I discuss the justification for this focus in greater detail in subsequent sections.

⁸The very fact that poor people have fewer possessions means there is less at risk of being destroyed by an extreme event. Thus, in theory there could be some positive relationship between wealth and economic impacts of extreme events (as suggested by e.g. Kellenberg & Mobarak, 2008).

it seems that credit constraints could be one important channel of transmission from transient shock to economic growth in poor countries.

Various studies (using microeconomic or case-study data) have shown that the investment decisions of poorer households tend to be constrained by their difficulty in accessing credit facilities. As a consequence, shocks to household income tend to have more persistent effects.⁹ In particular, these studies have found that poorer households are often forced to sell off productive assets in response to a negative weather shock, such as drought in Africa (see e.g. Scoones et al. 1996). Similarly, Jacoby and Skoufias (1997) have shown that poorer households are often forced to withdraw children from school as a means of coping with income shocks resulting from adverse weather conditions.

The literature on aggregate precautionary savings emphasises the role of uncertainty, or the volatility of income, in driving the demand for precautionary savings. Traditionally, aggregate (macro) volatility - which cannot be diversified nationally - was thought of as the main driver of precautionary savings at the macro level (Ghosh & Ostry, 1997). However, for developing countries with undiversified economies, or low levels of financial market development, idiosyncratic risks are also problematic to insure, leaving them vulnerable to random shocks (Acemoglu & Zilibotti, 1997) and also motivating the accumulation of precautionary reserves (Sandri, 2010).

If developing countries are characterised by higher macro volatility, lower diversity of economic activity or weaker financial sector development, then the requirement to accumulate precautionary reserves to insure against various forms of risk will lead to endogenously lower levels of productivity (Acemoglu & Zilibotti, 1997). Such circumstances may also be associated with the accumulation of foreign reserves (Aizenman & Lee, 2007) and capital flight (Aizenman & Marion, 1993), exacerbating conditions of capital scarcity often associated with low levels of economic development. As Tol & Leek (1999) have pointed out, precautionary savings (or equivalently, insurance premiums) are unlikely to be invested in risky locations.

Sandri (2010, p.11) also argues that “the precautionary motive becomes in-

⁹A version of the poverty trap.

finitely strong as safe assets shrink to zero and vanishes as they go to infinity". In this context, the interaction of poverty and exposure to natural hazards - through the mechanism of precautionary savings demand - should also be associated, *ceteris paribus*, with lower productivity and lower international investment flows.

1.2.3 Financial development and access to credit

The preceding discussion illustrates why credit may represent an important channel in the transmission of a transient shock to longer-term effects on growth. In Chapters 2 and 3 of this thesis I show in theory how a lack of access to credit constrains investment in human and physical capital in the aftermath of a shock, thus delaying recovery and potentially leading to longer-term effects from the shock. I test this result empirically using data on natural disasters and the level of credit to the private sector as a proportion of GDP, as a proxy for financial sector development. This credit variable was originally compiled by Levine *et al.* (2000). Those authors found this to be their preferred measure of financial development, and it has since become a standard proxy in the literature that uses cross-country data. Levine *et al.* (2000) argue that their credit measure is more than a simple measure of financial sector size, as it also isolates credit issued to the private sector, as distinct from credit to governments or the state-owned sector, and excludes credit issued by the central bank. Higher levels of private credit to GDP are therefore interpreted as indicating higher levels of financial services (including the key financial market functions of mobilizing savings, pooling risk and easing transactions).

However, this credit measure is of course imperfect and does not measure the provision of these financial services directly. It is also important to distinguish between the level of credit in an economy (as a proxy for financial depth) and *access* to credit. In the aftermath of a shock, the investment responses of households and small firms - particularly in developing countries - may be determined as much by their ability to access financial services as by the overall level of credit in the economy. While the two are likely to be related, ideally we would measure

directly the level of access to, and use of, financial services. Such data are generally only available through small scale, country-specific surveys. However, Beck *et al.* (2007) have compiled data on access to and use of financial services that is comparable across countries.

Unfortunately, these data have only been collected on a consistent, cross-country basis, in recent years. The first survey, reported in Beck *et al.* (2007) was carried out in 2003/4. This lack of a long time-series makes this data set unsuitable for the approach adopted in the analysis in Chapters 2 and 3. However, a more in depth exploration of the distinct role of access to financial services - as distinct from the broader measure of financial sector development used in this thesis - would be very worthwhile and is something that I intend to pursue beyond my doctoral studies.

For now, I take some comfort in the findings of Beck *et al.* (2007) who show that higher levels of financial ‘outreach’ (their measures of access to and use of financial services) are strongly and positively associated with traditional measures of financial sector development (such as the credit to GDP measure that I use in my analysis). I therefore assume that the credit measure is a proxy for the ability of firms and households to access financial services, albeit an imperfect one. Throughout the thesis, I use the terms credit access and financial sector development more or less interchangeably, notwithstanding the issues discussed in this section.

1.2.4 Trends in disaster vulnerability

The human and economic costs of natural disasters - and climate-related disasters in particular - have seen an increasing trend in recent years (Thomas, 2011; Loayza *et al.* , 2009; Raddatz, 2009). Some authors have linked these trends to the influence of anthropogenic global warming (e.g. Emanuel, 2005). However, as Tol & Leek (1999, p.320) point out, trends in damages are difficult to interpret “if the underlying socio-economic conditions are changing”. A recent review article concludes that once changes in the exposure of the human population and economic assets are taken into account, there is little evidence of increasing

trends in disaster intensity (Bouwer, 2011). Potentially important work remains to be done in attempting to extrapolate the likely future distribution of extreme weather events based on expected or observed changes in average temperature or precipitation patterns.

Low-income countries are uniquely vulnerable to natural disasters; both physically and economically vulnerable. As it is, these countries are on average warmer, and suffer from higher variability in rainfall than higher income countries (Stern, 2007). In economic terms, their greater vulnerability derives in part from the heavy dependence of poorer countries on agricultural output - a sector which is clearly weather-dependent. However, trends in vulnerability to natural disasters are ambiguous. Clearly, where there is little or no economic activity, vulnerability is low simply because there is not much around to be destroyed. Vulnerability, therefore, is increasing with economic activity, and also of course in the concentration of population. As incomes rise and people become more mobile they tend to move in greater numbers to attractive but vulnerable locations such as coastal areas.¹⁰

On the other hand, higher incomes are associated with higher expenditure on prevention and mitigation efforts, while higher wealth also tends to be associated with the availability of better technologies to mitigate disaster impacts. Kellenberg & Mobarak (2008) have suggested the idea of a non-linear relationship between income and natural disaster vulnerability, something akin to a ‘vulnerability Kuznets curve’. Thus, for very poor countries vulnerability may be likely to increase with development, at least initially, due to trends such as urbanization and the associated increase in population density, rapid growth of the population in absolute terms and a heavier geographic concentration of economic activity. These authors point out that “more people are now affected by natural disasters worldwide *despite* rising world income” (Kellenberg & Mobarak, 2008, p.790).

Development pressures have also been associated with increasing damage risks from natural disasters. For example, Kellenberg & Mobarak (2008) cite reported mangrove deforestation in Indonesia as a factor that exacerbated the devastation

¹⁰This point was first made in Dacy & Kunreuther (1969) in relation to the US, but the trend may not be repeated across all countries or cultures. For further discussion of economic vulnerability to disasters, see Cavallo & Noy (2009) and also Tol & Leek (1999).

of the December 2004 tsunami. Deforestation, for example in parts of South and Central America, has also been associated with more severe natural disaster impacts (UN, 2004; Albala-Bertrand, 1993). Rapidly rising populations also place extra strain on local environments and can lead to excessive demand for housing and other services. In such circumstances these are often either not supplied in sufficient quantity, or are provided hastily but in poor quality (Anbarci *et al.* , 2005).

This last point highlights the significance of political-economy factors in determining disaster vulnerability. Weak institutions, unsurprisingly, appear to be associated with more severe disaster impacts (e.g, Kahn, 2005; Noy, 2009). Political accountability and institutional capacity are crucial determinants of both disaster preparedness and the ability to respond quickly and effectively to the occurrence of a disaster event. However, it has been shown that voters are more likely to reward post-disaster rescue efforts - which are more visible - than preventative actions, which they hardly notice (Healy & Malhotra, 2009). Income inequality also matters. Anbarci *et al.* (2005) argue that greater inequality will exacerbate the difficulty of arriving at “an agreeable distribution of the burden of the necessary collective action” to mitigate the effects of natural disasters. In such circumstances, the relatively wealthy pursue self-insurance strategies, while the poor are left to the mercy of disasters.

Chapter 2

Natural disasters, credit constraints and economic growth

2.1 Introduction

The aim of this chapter is to examine theoretically and empirically the impacts of extreme events such as natural or humanitarian disasters on the prospects for long-term economic growth, with a particular focus on low-income economies. Despite the frequency of occurrence and potentially devastating effects of natural disasters (as demonstrated, for example, by the recent high profile earthquakes in Haiti and Japan), economists have had relatively little to say about how such events might impact, over the medium to long-term, on prospects for economic development. While disasters are by definition costly events - and therefore impose welfare losses on affected regions - their relevance to the prospects for economic growth in the affected region remains in dispute.

A recent review of the literature on the economics of natural disasters concludes that the long-term effects of disasters are as yet not well understood, while

in general the extant literature in this area is largely empirical and lacks any theory on the mechanisms and channels through which disasters might impact on economic growth (Cavallo & Noy, 2009). In this chapter, I present a specific mechanism of effect from disaster shock to economic growth (or recovery) - i.e. the availability of credit. I show that the medium-term dynamics of growth, in the aftermath of a disaster, are dependent on the level of financial sector development.

“The economic impact of a disaster depends to an important extent on the short-term characteristics of the economic situation at the time of the event.” (Tol & Leek, 1999, p.326)

One obvious effect of natural disaster events is to destroy physical assets such as infrastructure, buildings, machinery etc. The destruction of physical capital clearly has wealth effects. However, the consequences of such shocks for economic growth remain ambiguous *a priori*. In standard macroeconomic models, shocks of various kinds merely represent transient disturbances to the economic system. The resilience of the economy depicted in these models derives from its inherent flexibility. A shock that destroys capital will stimulate higher investment as the marginal product of capital rises in response to the fall in the capital stock. Thus the initial impacts of the shock are compensated by increased investment (Romer, 1986).

In theory, disasters could even be beneficial for economic growth. Reconstruction efforts may represent an old fashioned Keynesian type stimulus, particularly if the economy was operating below full capacity prior to the disaster occurrence. Similarly, the destruction of capital may represent an opportunity to replace what was destroyed with better technology or to upgrade infrastructure. In this case the shock of the capital destruction may represent a Schumpeterian “creative destruction” impulse to economic growth (as argued by Skidmore & Toya, 2002). However, the possibility of such a positive productivity effect resulting from a natural disaster occurrence has been disputed by Hallegatte *et al.* (2007), while Crespo Cuaresma *et al.* (2008) suggest that only developed countries are likely to benefit from any such mechanism.

Although growth theories have tended to discount the relevance of volatility and shocks for long run economic performance, it has been shown that volatility can affect welfare both directly, through consumption volatility (especially problematic for the poor who find it difficult to smooth consumption in the face of a negative income shock), and indirectly through its effects on economic growth (Loayza *et al.* , 2007). Empirical literature suggests that shocks can have significant effects on growth. Ramey & Ramey (1995) have demonstrated a negative link between volatility and economic growth, while some authors argue that volatility in growth can play a significant role in explaining cross-country economic performances (Easterly *et al.* , 1993; Collier & Dehn, 2001). Shocks and volatility induce uncertainty and make investment and liquidity constraints binding (Aizenman & Pinto, 2005). Such indirect impacts of volatility may be particularly deleterious in poor countries with weak “shock absorbers” (Loayza *et al.* , 2007).

The compensating mechanism described above depends on the presence of perfect credit markets. Following a disaster shock, which by its very definition has negative wealth effects, the ability of households to increase investment spending to compensate for the destruction of capital will depend crucially on the availability of credit. However, various studies (using microeconomic or case-study data) have shown that the investment decisions of poorer households tend to be constrained by their difficulty in accessing credit facilities. In particular, these studies have found that poorer households are often forced to sell-off productive assets in response to a negative income shock. As an example, following periods of severe drought in Africa, poorer farmers were found to be more likely to sell cattle and other forms of capital assets in order to survive (Scoones & Chibudu, 1996). Such a pattern is indicative of poorly functioning credit markets, while the resulting dis-investment is likely to exacerbate existing conditions of poverty.

Thus the transient shock of a natural disaster occurrence could have long term consequences as the growth potential of the economy is reduced through lower investment. Potentially, natural disasters could trigger a vicious cycle. Where credit availability is problematic, the shock of the disaster forces households to reduce productive investments, lowering future earning capacity. This in turn constrains the ability to make further productive investments into the future.

Such a scenario represents a simple version of the poverty trap. Poverty traps may also result from disaster shocks through the effects of disasters on human capital accumulation, as I discuss in the next chapter.

Sawada & Shimizutani (2008) use household level data to show that households facing a borrowing constraint were unable to maintain their consumption levels in the aftermath of the Kobe earthquake. This finding is suggestive of potential long-term consequences of the disaster shock (earthquake), at least for those households facing borrowing constraints. Similarly, Noy & Nualsri (2011) find that fiscal responses to natural disasters tend to be pro-cyclical in developing countries, potentially exacerbating the direct impacts of the disaster. Lis & Nickel (2010) also find that developing country governments experience a much larger deterioration in their fiscal positions following a disaster occurrence. However, the implications of their findings for subsequent economic growth are not explored by these authors. Noy (2009) analyzes disaster impacts at a macro level. Among the findings presented, disaster impacts on economic output are found to be more severe where financial sector development is relatively weak. However, that paper focussed on the contemporaneous effects of disasters and therefore may have missed the potentially important effects of financial sector development on the ability of an affected region to recover from disaster - which is the focus of this chapter.

Loayza *et al.* (2009) show that natural disasters have significant impacts on economic output in poor countries and not in rich countries, without presenting any evidence as to why this should be the case. Similarly, Raddatz (2007) shows that humanitarian and climatic disasters have persistent negative impacts on economic output in poor countries, without exploring the mechanisms behind this finding. There is also a significant macro literature on the welfare impacts of large economic “disasters” - i.e. large drops in output per capita (e.g., Barro, 2006; Gabaix, 2008). However, the focus of this literature is on the relationship between these economic disasters, asset prices and the implied welfare costs. The authors do not analyze the genesis of the large drops in output that they identify. As far as I am aware, the analysis presented here represents the first attempt to quantify the medium-term impacts of natural disasters at a macro level, and

to identify the circumstances under which such events have persistent effects on economic output.

In this chapter I focus on the effects of disasters on investment, for the following reason. For most disaster types, the major direct economic effects involve the destruction of physical assets and infrastructure. Economic recovery therefore requires investment in the affected region.¹ More generally, over the medium to long-term, what matters for economic development is the extent to which disasters impact on savings and investment decisions.²

I propose a simple theoretical model of the investment effects of natural disasters. I present two polar cases - in the unconstrained, small open economy agents have access to credit at a fixed world interest rate, whereas in the credit-constrained economy agents have no access to credit. The unconstrained version represents relatively rich countries with well developed financial markets and services, while the credit-constrained version reflects the difficulties faced by households in low-income countries in accessing banking services.³ A comparison of the results from the two model specifications is suggestive of the likely differences in impacts of disaster events across rich and poor countries.

The simplicity of the theoretical model may be viewed as a strength rather than a weakness. Using a standard neoclassical setup, I demonstrate that the transient shock of a disaster event should, in theory, have no long-term effects on the growth path of the economy. The introduction of a constraint on access to credit is sufficient, *on its own*, to generate persistent effects of the disaster shock on the path of economic output. The model therefore motivates the focus in the empirical analysis on the role of financial sector development as a determinant of the medium-term dynamics of growth in the wake of a natural disaster.

¹Even in the case of slow-onset events such as droughts and heat waves - for which the destruction of physical assets is not so immediately obviously - in the context of developing countries, important household assets such as livestock may still be destroyed and reinvestment required to compensate for the shock.

²Tol & Leek (1999, pg.311) argue that “the ‘only’ thing that counts ... is how [natural disasters] affect the propensity to save and (re)invest in the affected region.” The accumulation, through investment, of physical and human capital has long been seen as a key driver of long-term economic performance (e.g., Solow, 1956; Lucas, 1988; Mankiw *et al.*, 1992).

³For a review of the interaction between financial development and poverty or income inequality, see Demircuc-Kunt & Levine (2009).

The rest of the chapter is organized as follows. In the next section I discuss the links between natural disasters, economic volatility and economic growth. In Section 2.2 I present the theoretical model and derive results for the effects of natural disaster shocks on investment. In Section 2.3 I discuss the data and empirical framework used in my analysis, while sections 2.3.3, 2.3.4 and 2.3.5 include results of the empirical analysis and robustness checks. Section 2.4 concludes.

2.1.1 Disasters, volatility and growth

Natural disasters have often been characterized in reports by government and international agencies as a significant barrier to economic development.⁴ However this view has been criticised in some of the academic literature as empirically unfounded (e.g., Albala-Bertrand, 1993). Some studies have even found a positive correlation between disaster occurrences and economic growth (Albala-Bertrand, 1993; Skidmore & Toya, 2002).⁵

In the more recent literature, however, there appears to be an emerging consensus on the short-run economic impacts of natural disasters (e.g., Loayza *et al.*, 2009; Noy, 2009; Raddatz, 2007). What seems clear is that the economic impacts of disaster events will depend on a combination of the type and severity of the event, along with the underlying socio-economic and physical vulnerabilities of the affected region. In general the impacts appear to be negative, although for relatively mild shocks, the stimulatory impulse of reconstruction activity may dominate. Particularly damaging are extreme events such as severe storms and/or flooding, and prolonged periods of drought. Such events can overwhelm the coping capacities of the local economy, destroying infrastructure and crops, displacing

⁴See for example the 2002 United Nations International Strategy for Disaster Reduction (UNISDR) report “Natural disasters and sustainable development: Understanding the links between development, environment and natural disasters”.

⁵As mentioned, possible explanations for this positive relationship include a Keynesian type stimulus from reconstruction activity, or a Schumpeterian ‘creative destruction’ effect. However, this idea has been disputed by e.g. Hallegatte & Dumas (2009) and Crespo Cuaresma *et al.* (2008), while Tol & Leek (1999) have pointed out that such positive results could be due to the fact that standard economic indicators (such as GDP) measure flows, while natural disasters tend to impact on stocks.

populations and in some cases leading to disease outbreaks.⁶

Natural disasters predominantly occur in the so-called developing world. According to the World Bank, 97% of natural disaster related deaths occur in developing countries, while economic losses as a proportion of GNP in poor countries far exceed those in the rich world.⁷ Low-income economies are also vulnerable to extremes of weather and other disasters due to economic and institutional factors. Poorer countries tend to be highly dependent on agricultural production, a sector which is clearly weather-dependent. Furthermore, weak institutions in developing countries make them less able to cope with, and prepare for, extreme event occurrences.⁸

However, with the assumption of complete markets, agents should be able to trade risk through financial and insurance markets, thereby avoiding turning production or income volatility into consumption and investment volatility (Aufret, 2003). Thus shocks should have only transient effects on economic output - a theoretical result that has long consigned short-run shocks to a position of relative insignificance within the literature.

Tol & Leek (1999, pg.326) argue that “[t]he economic impact of a disaster depends to an important extent on the short-term characteristics of the economic situation at the time of the event.” They evaluate natural disasters in a Keynesian framework, interpreting natural disasters as a negative shock to capacity and the subsequent reconstruction activity as a positive shock to demand. Natural disasters are therefore particularly problematic in a booming economy, and may even have positive effects during a recession, particularly if reconstruction mobilizes otherwise inaccessible reserves such as insurance cover. Tol and Leek’s dual nature of disasters - an output shock followed by a reconstruction effort - also highlights the crucial role of capital markets in the economic impact.

Although growth theories have tended to discount the relevance of volatility and shocks for long run economic performance, it has been shown that volatility

⁶A detailed analysis of the short-run effects of various disaster types is reported in a recent World Bank Policy Research Working Paper (Loayza *et al.* , 2009).

⁷As cited in the 2002 UNISDR report mentioned above.

⁸The literature on the economic effects of natural disasters suggests that weak institutions are associated with more severe impacts (e.g., Kahn, 2005; Noy, 2009).

can affect welfare both directly, through consumption volatility - especially problematic for the poor who find it difficult to smooth consumption in the face of a negative income shock - and indirectly, through its effects on economic growth (Loayza *et al.* , 2007).

Traditionally there has been a dichotomy within macroeconomic theory between the economics of the short and long-run (Solow, 2005). Neoclassical growth models depict economies that converge smoothly to steady-state growth paths.⁹ However, in a seminal contribution, Ramey & Ramey (1995) demonstrated the negative link between volatility and economic growth. Negative shocks and volatility induce uncertainty and make investment and liquidity constraints binding (Aizenman & Pinto, 2005). Such indirect impacts of volatility may be particularly deleterious in poor countries with weak shock absorbers.¹⁰

For poor households, the long-term impacts of income volatility are especially damaging. In times of scarcity or following income shocks, the availability of credit allows households to smooth consumption while continuing to make valuable investments for the future. In the absence of well developed financial markets, liquidity constraints may cause income shocks to have more significant long-term effects. Thus, not only is lifetime wealth reduced directly by the destructive effects of the shock, but the effect is compounded for poorer households whose future earning potential is also reduced through the forced disinvestment of productive assets.¹¹

Low-income economies generally tend to have less well developed financial sectors than richer ones. Several studies have demonstrated the link between financial sector development and economic growth (e.g., Levine, 1997; Levine *et al.* , 2000). More recently, Aghion *et al.* (2005) demonstrated that the presence of credit constraints can amplify the growth effects of economic shocks. It is this type of mechanism which is the focus of this chapter.

⁹In a celebrated series of lectures, Robert Lucas argued that business cycle fluctuations were relatively unimportant for welfare (Lucas, 1987).

¹⁰Relevant shock absorbers might include developed financial markets and counter-cyclical fiscal policy (Loayza *et al.* , 2007). See also Tol & Leek (1999), for a discussion of the importance of insurance and financial reserves in coping with natural disasters.

¹¹This point is made in Jacoby & Skoufias (1997). For evidence of this type of behaviour see Scoones & Chibudu (1996) and Rosenzweig & Wolpin (1993).

The emphasis here on extreme events (i.e. natural disasters) is further justified by the findings of Hnatkovska & Loayza (2005) who show that it is not the volatility due to normal fluctuations, but rather the volatility due to crises, that harms economic growth over the long-run. Furthermore, there is an increasing awareness among macroeconomists of the need to take account of the possibility of extreme (rare or unlikely, but large) events. This point is made by Cavallo & Noy (2009) and, in a slightly different context, by Paul Krugman.¹² In the context of climate change impacts, the need to take account of the probability distribution of events, rather than simply the mean or most likely event scenario, has been highlighted by Hallegatte *et al.* (2007) and more recently by Hendry (2010).

2.2 Modelling the investment effects of disasters

In this section I present my theoretical model. A simple two-period framework is used to model the macroeconomic impacts of extreme events, as follows:¹³

Agents maximize utility

$$U = \ln(C_1) + B\ln(C_2) \quad (2.1)$$

subject to

$$C_1 + RC_2 = F(K_1, L_1) - I_1 + RF(K_2, L_2) \quad (2.2)$$

where periods are subscripted 1 and 2. The production function $F(\bullet, \bullet)$ is assumed to be at least twice continuously differentiable and to exhibit constant returns to

¹²“How did economists get it so wrong?” New York Times Magazine, 9/2/2009, as cited by Cavallo & Noy (2009, pg.32).

¹³The basic structure of the two-period model follows Barry (1999). Detailed, step-by-step derivations of results are included in the mathematical appendix.

scale in its two arguments. B is the discount factor and R is the interest factor (i.e. one over one plus the interest rate). For the unconstrained small open economy, the interest rate is an exogenous, risk-free world interest rate. Utility depends on the level of consumption in each period. Leisure is excluded from the utility function, as an unnecessary complication. We assume that labour is supplied inelastically, and normalise the labour supply in each period to unity in order to focus exclusively on the investment effects of a shock that destroys capital. The economy is endowed with a stock of physical capital in period 1 (K_1) which is combined with labour to produce a single good used for both consumption and investment. Thus, capital is accumulated through foregone consumption. It is assumed that capital must be accumulated one period in advance of use, and therefore no investment takes place in period 2:

$$K_2 = K_1 + I_1 \quad (2.3)$$

Using equation (2.3) we can rewrite the budget constraint (2.2) as follows

$$C_1 + RC_2 = F(K_1, L_1) - I_1 + RF(K_1 + I_1, L_2) \quad (2.4)$$

The first-order conditions for the solution of the maximization problem are then

$$C_2 = C_1 \left(\frac{B}{R} \right) \quad (2.5)$$

and

$$RF_{K_2} = 1 \quad (2.6)$$

Equations (2.5) and (2.6) represent the inter-temporal efficiency conditions for effective consumption and investment. Optimal investment in physical capital involves equating the return on capital (the marginal product of capital in period 2, F_{K2}) with the interest rate. Discounted disposable lifetime income (after investment) is then divided between consumption in each period according to (2.5).

One obvious effect of natural disasters is the destruction of physical capital in the form of homes and other buildings, infrastructure, livestock etc. Following a disaster occurrence, the path of the capital stock will depend on the combined effects of the amount of capital destroyed by the event and the capital accumulated through new investments.

If we assume a Cobb-Douglas production function, such as

$$Y = K^\alpha L^{(1-\alpha)}$$

where α and $(1 - \alpha)$ represent the capital and labour elasticities respectively, with $0 < \alpha < 1$, we can rewrite (2.6) as follows

$$\alpha(K_1 + I_1)^{(\alpha-1)} L_2^{(1-\alpha)} = \frac{1}{R} \quad (2.7)$$

giving

$$I_1 = \left(\frac{1}{\alpha L_2^{(1-\alpha)} R} \right)^{1/(\alpha-1)} - K_1 \quad (2.8)$$

This implies that, in equilibrium for the unconstrained economy (with exogenous interest rate)

$$\frac{dI_1}{dK_1} = -1 \quad (2.9)$$

That is, any shock that destroys a portion of the capital stock in the first period is exactly compensated by increased investment so that the capital stock in the second period is unaffected.

In a credit-constrained economy, with no access to world capital markets, the interest rate is no longer an exogenous world rate, but rather an endogenously determined rate (that serves to clear the goods market in each period). Assuming once again a Cobb-Douglas production function, as above, equation (2.7) can be used to express R as follows

$$R = \frac{1}{\alpha(K_1 + I_1)^{(\alpha-1)}L_2^{(1-\alpha)}} \quad (2.10)$$

Now that R is no longer fixed, we need to consider how it will vary in response to a shock to the capital stock. Differentiating equation (2.10) with respect to K_1 , we have

$$\frac{dR}{dK_1} = \frac{-(\alpha - 1)(K_1 + I_1)^{\alpha-2}}{\alpha L_2^{(1-\alpha)}(K_1 + I_1)^{2\alpha-2}} > 0 \quad (2.11)$$

given that we assumed $0 < \alpha < 1$ and therefore $(\alpha - 1) < 0$.

This expression for dR/dK_1 implies that a shock that destroys a portion of the capital stock will raise the interest rate (recalling that R is the interest factor, i.e. one over one plus the interest rate). This makes intuitive sense, given the expected effects of scarcity on the cost of capital following a disaster occurrence.¹⁴

Returning to our equation for I_1 from above (equation 2.8) it is clear that the presence of R in this equation implies that, for the credit-constrained economy,

¹⁴Another way of thinking about this is to consider R as the endogenous discount factor in the closed economy. In the aftermath of a disaster occurrence, people will discount the future more heavily as they prioritise short-term survival. This interpretation reflects the empirical evidence from microeconomic studies, discussed above in section 2.1.1, which shows that poor households are often forced to sell-off productive assets in the aftermath of natural disaster events.

investment will no longer compensate fully for a shock to the capital stock, meaning that the future capital stock will be permanently lower than it would have been in the absence of the shock. In fact equation (2.9) now becomes

$$\frac{dI_1}{dK_1} = \left\{ \left(\frac{1}{R\alpha L_2^{(1-\alpha)}} \right)^{[1/(\alpha-1)]-1} \cdot \left[\frac{(K_1 + I_1)^{\alpha-2}}{(R\alpha L_2^{(1-\alpha)})^2 (K_1 + I_1)^{2\alpha-2}} \right] \right\} - 1 \quad (2.12)$$

which is clearly > -1 .¹⁵

A rising interest rate (in response to the shock) reduces the absolute value of dI_1/dK_1 , or, in other words, reduces the responsiveness of optimal investment to shocks to capital. Thus, for the credit constrained economy, the shock to the capital stock following a natural disaster event is no longer fully compensated by investment.

2.3 Empirical analysis

The theoretical analysis contained in the preceding section presents a clear testable hypothesis: The shock of an extreme event occurrence will have more severe and/or more persistent (i.e. longer lasting) effects on economic output where access to credit is problematic. I test this hypothesis using a comprehensive panel dataset of natural disaster events at the country level, for the period 1979-2007.

2.3.1 Data and summary statistics

The data on natural disaster events are obtained from EM-DAT, the international emergency events database maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the Catholic University of Louvain in Belgium. This dataset covers all major natural disaster events across 180 countries for the

¹⁵See the mathematical appendix for a step-by-step derivation of this result.

period 1960-2009. I restrict my analysis to the period 1979-2007 for reasons of data quality and completeness.

The EM-DAT database includes data on the number of people killed and the total number affected (including those injured, made homeless or otherwise displaced) by a disaster event. The dataset also contains estimates of the economic costs of disaster events. However, these economic data are not considered to be reliable as there is no systematic way of collecting damage cost data in the aftermath of natural disasters. The humanitarian and medical personnel present after a disaster have had no training in economic damage assessment and are, in any case, otherwise occupied. I therefore concentrate on the numbers killed or otherwise affected by disasters in constructing the measures of natural disasters.

I construct two measures of disasters for use in my analysis - a continuous measure and a binary measure. The continuous measure is defined as follows:

$$Disaster_{it} = \ln \left(1 + \sum_j \frac{TotalAffected_{it,j}}{Population_{i,t-1}} \right) \quad (2.13)$$

where j indexes the number of events recorded in country i in period t . The sum of the total number of people affected by disasters per country-year observation is normalized by the size of the population of the country in order to facilitate comparison across countries.¹⁶ The skewed nature of the distribution of this disaster measure leads us to take logs in order to reduce the influence of outliers on our results.

Descriptive statistics, based on the proportion of the population affected by disasters (and conditional on there being an event in a given country-year) are included in Table 2.1. There are 2,123 country-year observations in the data that include at least one disaster. The average disaster affects 3.8% of the population. However, the largest observation in the data is over 150% of the population affected by disasters in a single year (recall that the measure involves the sum of all disasters in a given country-year). Clearly such large values might be considered

¹⁶The population from the previous period ($t-1$) is taken to avoid the denominator being dependent on the numerator in the equation for $Disaster_{it}$.

outliers and thus have an undue influence on our results. In fact, a closer inspection of the distribution of this series (not reported) reveals that in 99% of cases where disasters were reported less than 61% of the country's population were affected, while in 95% of cases less than 21% of the population were affected. In the analysis reported below, I show that my results gain in significance if I omit the top 1% (or 5%) of the disaster distribution, lending further support to the idea that these large values represent outliers in the data.

Looking at events by type, we see that hydrological events (e.g. floods) were the most frequent events reported, with 1,292 country-year observations including at least one event in this category. The frequency of events across the other event types are fairly evenly distributed, at between 400 and 700 country-year observations. When it comes to event severity, there appears to be substantial variation across event types, based on the proportion of the population affected. Weather events (e.g. droughts and heat waves) are the most severe event category, according to this measure, affecting 9.2% of the population on average, while meteorological events (e.g. storms) are the next most severe event category, affecting 3.4% of the population on average. These two categories also record the largest maximum values (152% and 116% respectively). Water-related events affect 1.3% of the population on average, while geological events (such as earthquakes and volcanoes) and biological events (e.g. epidemics) on average only affect 0.6% and 0.2% of the population respectively.

The second disaster measure that I construct is a binary measure, which takes a value of 1 if:

$$\Sigma_j \frac{TotalAffected_{it,j}}{Population_{i,t-1}} > 0.005 \quad (2.14)$$

The motivation for using such a binary measure of disasters is to reduce the potential endogeneity of the disaster measure with respect to economic development. The effects of disasters, in terms of the numbers of people killed or affected, are dependent to some extent on various socio-economic factors (Sen, 1983; Kellen-

berg & Mobarak, 2008). For this reason, it may be questionable to assume the exogeneity of disasters (as measured by the number of people affected) with respect to economic development. The use of a binary definition of disasters reduces the potential influence of endogeneity on our results. Furthermore, the specification of our empirical model - using panel data and including country fixed effects - places the emphasis for identification of effects on the within country variation over time. This approach reduces the influence of any potential selection bias that might arise, for example, if poorer countries were over-represented in the disaster data due to the likelihood that disasters would affect a greater proportion of the population in poor countries.

The binary measure gives equal weight to all disaster events. This inevitably reduces the variation in the data, and potentially the explanatory power of the data. However, this also has the advantage of reducing the potential influence of measurement error in the natural disaster data and of outlier events at the upper end of the disaster distribution. The imposition of the minimum threshold for the binary measure is also important to avoid giving undue importance to relatively minor events.

Table 2.2 shows the frequency of disasters that exceed the 0.5% threshold. While 43% of all country-year observations include some reported disaster, just 17% of observations include disasters that affect at least 0.5% of the population. Clearly a substantial proportion of events included in the data are relatively minor and thus may have little or no explanatory power when it comes to the effects of disasters on economic output.¹⁷ Looking at specific disaster types, again flood events are the most frequent (at 7.8% of country-year observations exceeding the 0.5% threshold), although the difference in frequency versus other types is less here than using the continuous measure, suggesting that a relatively large proportion of flood events in the data are comparatively minor events. Weather events that exceed the threshold also occur with relative frequency in the data (at about 5% each). However, it appears that relatively few biological or geological

¹⁷In fact, when I try running the main model specification without the imposition of a minimum threshold on the binary disaster measure, the results remain very similar, albeit with the magnitude of the coefficients on the disaster measure and its interaction with credit slightly reduced.

events affect a significant proportion of the population, with just one in one hundred country-year observations including events of these types that exceed the 0.5% threshold.

The credit measure that I use to proxy for the level of financial sector development is the level of credit to the private sector as a proportion of GDP, as originally compiled by Levine *et al.* (2000).¹⁸ The annual series for this measure is taken from the World Bank's World Development Indicators (the original data are from the IMF's International Financial Statistics). However, on closer inspection, this data series contains some unrealistically large observations for a number of Eurozone countries. The cause of these anomalous observations has not yet been identified; therefore I was forced to omit the affected countries from the current version of the analysis.¹⁹ We thus have a panel dataset with 170 countries, covering the period 1979-2007.²⁰

Data on economic growth and income levels come from the Penn World Tables version 6.3. Other economic indicators are from the World Bank's World Development Indicators.

Table 2.3 includes summary statistics on the three main variables of interest for our sample, divided by rich versus poor countries. Countries were labelled rich or poor in the dataset based on whether they were above or below the median

¹⁸In the results reported below, I restrict the analysis to countries in which average credit to the private sector is greater than 10% of GDP. According to Aghion *et al.* (2005, pg.17): "variation in the measure of credit within the 0 – 10% range is unlikely to be informative about the variation in the availability of funds". However, my results remain robust to the removal of this restriction, or to variations involving a higher threshold.

¹⁹The eight countries omitted on the basis of this data problem were: Austria, Belgium, Finland, France, Italy, Luxembourg, Portugal and Spain.

²⁰The panel is unbalanced as the credit measure that I use was not available for every country-year in the dataset. As a check on the robustness of the results reported below, I also tried using average credit as a % of GDP for each country over the sample period, interacted with the disaster measure. The results are reported below. I also tried running all of the regressions using a sample that omits countries for which we do not have complete data on economic growth over the sample period (1979-2007). This resulted in the omission of a further 27 countries: the 15 former Soviet states (Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine and Uzbekistan) the seven former Yugoslav states (Bosnia and Herzegovina, Croatia, Kosovo, Macedonia, Montenegro, Serbia and Slovenia) the former Czechoslovakia (Czech Republic and Slovakia) as well as Eritrea, Yemen and Timor-Leste. The results from these regressions were very similar to those reported below using the full sample.

income level in the data for the year that they enter the sample. As we might expect, the table shows that poor countries on average suffer more severe effects from disasters and have lower levels of credit than their rich counterparts. Poor countries grow faster on average over the sample period, although this growth is more volatile.²¹

2.3.2 Empirical strategy

In the empirical analysis, reported below, I run panel regressions of the following form

$$\Delta y_{it} = \beta_0 + \beta_1 y_{i,t-2} + \beta_2 D_{it} + \beta_3 credit_{i,t-1} + \beta_4 D_{it} * credit_{i,t-1} + \theta_i + \theta_t + \epsilon_{it} \quad (2.15)$$

where Δy_{it} represents the annual growth rate of output per capita in country i for period t .²²

A lagged income term ($y_{i,t-2}$, income per capita in logs, lagged two periods) is included to capture convergence effects.²³ The credit measure (used to proxy for

²¹It is also worth noting the very large values (in absolute terms) for the min and max observations of annual output growth in both rich and poor countries. One might be concerned that the results would be driven by these outliers. To ensure this is not the case, I check the robustness of my results to the exclusion of the top and bottom 1% of the annual growth distribution.

²²A dynamic panel estimation strategy (e.g. system GMM or panel VAR) was also considered as an alternative to the fixed effects model adopted here. However, these models are not without their own problems, for example the weak instrument problem discussed by Bun & Windmeijer (2010). There is also the danger of creating a false sense of certainty, due to a large number of internal instruments over-fitting the endogenous variables (see Roodman, 2009). Perhaps most problematic for my purposes, is the assumption of a common lag structure across observational units (see discussion in Herzer *et al.*, 2012). This assumption would appear difficult to justify for my data, given that my sample includes 170 countries with widely varying growth experiences. Furthermore, one of the main aims of my analysis is to demonstrate that the lag structure of growth following a disaster shock differs across countries depending on their level of financial sector development. For this reason, the more straightforward fixed effects panel data model was preferred. An error correction model could also have been used in the analysis and is quite similar to the autoregressive distributed lag model used as a robustness check on the results in Section 2.3.5.

²³This functional form is based on a model used by Aghion *et al.* (2005) in their investigation of the growth effects of commodity price shocks in the presence of credit constraints. I generally

the level of financial development, as described above) enters as $credit_{i,t-1}$. The first lag of credit is taken to avoid the occurrence of a disaster contemporaneously influencing the level of credit.²⁴

I interact the credit measure with the disaster variable in order to test directly the hypothesis that countries with less well developed financial sectors (i.e. where agents face credit constraints) suffer more severe growth effects from natural disasters. If the hypothesis is correct, then we would expect to find a positive coefficient on the interaction term, indicating that greater financial development mitigates the growth effects of disasters (a higher value of the credit measure represents a greater degree of financial sector development). To control for any omitted country-specific, time-invariant factors, I include country fixed effects (θ_i) and cluster errors by country. I also include time fixed effects (θ_t) to control for shocks that affect all regions simultaneously. Essentially this term should capture the world business cycle.

I also run versions of the above model including up to ten lagged observations of the disaster measure and the interaction of disasters with credit access. This model enables us to assess the medium-term dynamics of the interaction between natural disaster events, credit constraints and economic growth.

2.3.3 Contemporaneous effects of disasters on growth

Table 2.4 presents results of regressions using the binary measure (=1 if > 0.5% of the population is affected). To begin with I run models without any lags, focussing on the contemporaneous effect of disaster events on economic growth, and attempting to identify the most important channels of effect. In model (1), without any interaction terms included, we find that any disaster that exceeds the 0.5% threshold reduces contemporaneous growth by 0.94 percentage points. In

found evidence of strong short-term convergence effects in the data, while I also experimented with different lags of income per capita and found the results were robust to these variations in specification.

²⁴Variations on the main specification show that the results remain robust, albeit with some loss of significance, when using average credit over the sample period or contemporaneous credit, instead of the lagged term.

model (2) I include the interaction of the disaster measure with credit availability (the main focus of my study). We find a positive and significant coefficient on the interaction term, suggesting that greater access to credit helps to mitigate the effects of natural disaster events on economic growth. In terms of quantifying this effect, if we take a country with a relatively low level of financial development such as Burkina Faso (with an average credit to GDP ratio of about 13% over the sample period), according to my results a disaster event will reduce contemporaneous output growth by around 1.25 percentage points. By comparison, a country with a modest level of financial development, such as the Czech Republic (with an average credit to GDP ratio of about 53% over the sample period - representing the average for 'rich' countries in our sample) would only see its output growth in the year of a disaster reduced by around 0.15 percentage points.²⁵

Models (3), (4) and (5) include various checks on the robustness of these results. In model (3) I use period average credit, instead of the lagged credit term. This is to confirm that the results are not being driven by business cycle effects related to the level of credit in the period immediately preceding a disaster event. Although there is some loss of significance on the interaction term, the results in model (3) would seem to indicate that business cycle effects are not driving my findings.

In model (4) I include the interaction of disasters with a poor dummy (= 1 if the country had below median income per capita in the year it entered the dataset). The results on the interaction between disasters and credit remain robust to the inclusion of the poor country dummy.

Finally, in model (5), I introduce an interaction between the average share of agriculture in total output (*AgriShare*) and the disaster measure. Given that many types of disasters (such as floods and droughts) are likely to have a direct impact on agricultural output, it may be that the degree of economic dependence on agriculture could represent a distinct channel of effect from disasters to economic growth. However, the results presented here are somewhat ambiguous on this point. The interaction between *AgriShare* and the disaster measure does

²⁵For Burkina Faso, the effect on output growth is: $(-1.6117) + (0.0275) \cdot (13) = -1.2542$. For the Czech Republic, the effect is: $(-1.6117) + (0.0275) \cdot (53) = -0.1542$.

not enter significantly in the regression. Interestingly, the disaster measure itself also loses significance in this model.²⁶ However, the coefficient on the interaction between disasters and credit remains (marginally) significant, and of a similar magnitude to the other versions presented in this table.

Based on the results presented here, it appears that access to credit represents a significant channel of effect from disasters to growth, and is not simply a proxy for poverty or economic structure (i.e. dependence on agriculture). These preliminary findings would seem to support the predictions of the theoretical model. Where access to credit is problematic, countries suffer more severe output effects from the occurrence of natural disasters.

In Table 2.5 I present regression results using the continuous measure of disasters, as defined above. When the full sample of disaster events is included, in model (1), the results are not significant using this disaster measure. However, as discussed above, the full sample of disaster events includes some large outlier events. I therefore repeat the regression excluding the top 1% of the disaster distribution in model (2) where the results gain some significance, and excluding the top 5% of the disaster distribution in model (3) where the results become highly significant.

Again, we can illustrate the magnitude of the effects, based on the continuous measure (and excluding the top 5% of the disaster distribution), using the exemplars of Burkina Faso and the Czech Republic.²⁷ For a country with the level of financial development of Burkina Faso, an average disaster event (i.e. one that affects 3.8% of the population) would reduce growth contemporaneously by approximately 0.69 percentage points. The same event occurring in a country with

²⁶The ambiguity of these results may be explained by the counter-vailing effects of agricultural dependence for different types of disasters. Dis-aggregating by disaster type (results not reported), we find that higher agricultural dependence does indeed appear to be associated with more negative effects of climatic disasters - i.e. droughts and extreme temperatures - on output growth, as one might expect. For storms and floods, however, the opposite appears to be the case. Greater agricultural dependence appears to be associated with a positive relationship between storms (or floods) and economic growth. This finding may simply reflect the positive effects of higher rainfall (which is likely to coincide with storm and flood events) on agricultural output, as posited by Loayza *et al.* (2009).

²⁷Recall that the continuous disaster measure enters the regression as $\ln(1 + \text{the \% of the population affected})$.

the level of financial development of the Czech Republic, would not reduce contemporaneous output growth.²⁸ Again, the results using the continuous measure would seem to support the predictions from the theoretical section.

2.3.4 Dynamics of disasters and growth

In Table 2.6 I present results from models that include up to 10 lags of the disaster measure (and the interaction of disasters with credit availability). These models enable us to attempt to tease out the medium-term dynamics of disaster effects on economic growth. The results presented in the table represent the sum of the contemporaneous and lagged effects for each model.²⁹

An interesting pattern emerges in the reported results as further lags of disasters are added. We see that the sum of coefficients on the disaster measure becomes increasingly negative as more lags of this measure are added, indicating that the effects of disasters are persistent over time.³⁰ The results also show that credit access maintains its importance as further lags are added.

To interpret the quantitative significance of these results, we can once again use the exemplars of Burkina Faso and the Czech Republic. For a country with Burkina Faso's level of financial sector development, the cumulative effect of the disaster on output growth intensifies over time (albeit the largest marginal effect of disasters on growth is in the year of the event), from -1.49 percentage points (with no lags) to -2.61 (three lags), -2.82 (five lags) and -4.12 (with ten lags). These results clearly represent economically meaningful effects. For a country with a credit to GDP ratio of between 10% and 30%, average annual growth in my sample is 1.07%. Thus for a country with the level of financial development of Burkina Faso, a disaster would completely wipe out economic growth for up

²⁸For Burkina Faso: $(-24.6804) \cdot \ln(1 + 0.038) + (13) \cdot (0.4754) \cdot \ln(1 + 0.038) = -0.69$. For the Czech Republic: $(-24.6804) \cdot \ln(1 + 0.038) + (53) \cdot (0.4754) \cdot \ln(1 + 0.038) = +0.02$.

²⁹The significance levels (standard errors and t-statistics) for the cumulative coefficients (i.e. the sum of the contemporaneous and lagged effects) were calculated using the *lincom* command in Stata.

³⁰Note that in the model with one lag of disasters added the results are no longer significant, suggesting that some recovery from the disaster does take place in the period immediately following the occurrence of the disaster event.

to three years.

For a country with an intermediate level of financial development, such as the Czech Republic, on the other hand, the effect of a disaster is mitigated over time, with the negative impact disappearing after a year.³¹ The results suggest that disasters have persistent as opposed to transitory effects where credit access is problematic, thus supporting the predictions of the theoretical model.

2.3.5 Robustness checks

In this section, I present a range of robustness checks on the findings relating to the medium to long-term dynamics of disasters. The findings suggest that the results reported in the previous section are extremely robust to various changes in the specification of our model.

One concern with the results might be the potential for serial correlation in the time-series on economic growth. For this reason, I repeat the analysis of the dynamics of disasters and growth using a panel autoregressive distributed lag (PARDL) model. In this model I include lags of growth in the regressions. Results in Table 2.7 are almost identical to those presented previously, although there is some loss of significance at 10 lags.³²

In Table 2.4, we saw that the inclusion of the interaction between disasters and agricultural dependence caused the disaster measure to lose significance, indicating an ambiguous relationship between agricultural dependence and the short run effects of disasters on economic growth. We want to be sure that the results we have reported for the medium term effects of disasters on growth are not contingent on the level of agricultural dependence. I therefore repeat the analysis contained in Table 2.6, this time including the interaction between disasters and the average level of agricultural dependence (defined as the share of agriculture in total output) as a separate regressor. As demonstrated in Table 2.8, the results

³¹The calculations used to derive these quantitative effects involve: (sum of disaster coefficients) + (sum of interaction term coefficients)*(credit as % of GDP).

³²Autocorrelation does not appear to be a significant problem in the dataset. The correlation of the residuals in the contemporaneous model is only 0.05, and this disappears once lags of growth are included.

remain robust to the inclusion of this interaction term. The *disaster * credit* interaction term is significant at 3, 5 and 10 lags, while the disaster variable itself gains significance at 10 lags. While the degree of dependence on agriculture may be an important determinant of the contemporaneous (or short-term) effects of disasters on economic growth, over the medium to longer-term, access to credit appears to play a more significant role in determining the persistence of these disaster effects.

I also repeated the analysis on a dataset that excludes those countries for which complete economic data were not available. The results from this analysis (not reported) were almost identical to those presented in Table 2.6. Further checks on the robustness of the results included varying the lagged income variable used to capture short-term convergence effects, variations on the restrictions imposed on average credit, and the exclusion of what might be considered outliers in terms of economic growth (i.e. the exclusion of annual growth observations in the top and bottom 1% of the distribution of that series). I also repeated the main specification using different minimum threshold levels for the binary disaster measure, including a version without any minimum threshold (i.e. including all events recorded in the EM-DAT database). The findings remained qualitatively unchanged (and indeed quantitatively very similar also) for all of these specifications.

2.4 Conclusions

In the theoretical analysis, I demonstrate that the growth prospects of a rich world economy are unlikely to be affected by the occurrence of an extreme event such as a natural disaster. While output may fall temporarily, due to the disruption caused by the disaster, I have shown that, given access to credit, increased investment will fully compensate for any losses to the capital stock, returning the economy to its pre-shock long-term growth path.

The case of a low-income economy, on the other hand, is not so straightforward. I have modelled the representative poor country as having no access to

world capital markets, to reflect the difficulties faced in poorer countries with regard to accessing credit and banking services. For the credit-constrained economy, I have shown that a disaster occurrence will not be fully compensated by increased investment. These investment effects will leave the economy permanently worse off in terms of output. Thus, a disaster occurring in a relatively poor country will not only reduce output in the short-term, but will, *ceteris paribus*, reduce the growth rate of the economy in the medium to long-term.

Results from empirical analysis aimed at testing the implications of the model would seem to support the hypothesis that the availability of credit may be a significant factor in determining the economic impacts of natural disasters. The role of credit access appears to be a distinct channel of effect from disasters to economic growth, and not just a proxy for related factors such as poverty or economic structure (i.e. dependence on agriculture).

I find that credit constrained economies are likely to suffer more severe and more *persistent* effects of disasters on economic growth. For countries with relatively weak financial sector development, the cumulative effect of a disaster event on economic growth remains significantly negative at up to 10 lags from the disaster event, thus lending support to the idea that disasters - while themselves transitory in nature - can have important medium-term growth effects for less developed economies. In terms of quantifying this effect, I find that for a country with relatively low levels of financial development, a disaster event could completely wipe out economic growth for up to 3 years, with the effects continuing to be significant 10 years after the occurrence of a natural disaster. In contrast to some of the existing literature, my findings suggest that natural disasters do represent significant threats to economic development in poor countries.

While the empirical model used here appears to be capable of identifying the kind of effects we are interested in, one potential criticism of my approach is that it is excessively parsimonious, in that the only control variables included in the baseline specification are time and country fixed effects and a lagged income measure. In particular, one might be concerned that institutional or policy variables - for example building codes, planning legislation or a country's institutional capacity to respond to a disaster event - might be mediating the observed relationship

between disasters and growth. However, to the extent that these factors do not vary much within a given country from year to year, their inclusion should not alter my findings, which are based on the within country variation over time in our data. One would not generally expect institutional variables to vary much from year to year for a given country.

Future analysis might also include Official Development Aid (ODA), and non-disaster shocks such as terms of trade or exchange rate changes. Such analysis would require a different empirical model, given the likely endogeneity of at least some of those factors mentioned. A panel VAR model (as used in Raddatz, 2007) or a system GMM (as used in Levine *et al.* , 2000) would allow for the inclusion of potentially endogenous control variables.

Table 2.1: Event severity by % of population affected

Event Type	Description	Obs	Mean	Std. Dev.	Min	Max
All Events	Total Affected	2123	3.80	11.86	6.14e-06	151.82
Biological	Epidemics	574	0.20	1.30	6.85e-07	25.13
Climatological	Droughts	407	9.24	18.82	2.25e-06	116.15
Geological	Earthquakes	441	0.60	03.10	5.03e-07	48.30
Hydrological	Floods	1292	1.26	3.73	2.39e-06	41.64
Meteorological	Storms	682	3.37	12.61	1.39e-06	151.82

Table 2.2: Event frequencies by events exceeding threshold

Event Type	Description	Frequency (% Country-Year Obs.)
All Events	Total Affected (> 0)	42.56%
All Events	Total Affected (> 0.5% of Pop.)	16.86%
	<u>> 0.5% of Population Affected</u>	
Biological	Epidemics	0.98%
Climatological	Droughts	5.01%
Geological	Earthquakes	1.34%
Hydrological	Floods	7.82%
Meteorological	Storms	4.93%

Table 2.3: Summary statistics: Rich versus poor countries

Variable	Mean	Std. Dev.	Min	Max
<u>Rich</u>				
Disasters (% of Pop Affected)	2.22	9.55	6.14e-06	121.71
Avg. Credit (% of GDP)	53.04	38.87	2.80	182.11
Annual Growth (%)	1.67	6.73	-64.36	49.86
<u>Poor</u>				
Disasters (% of Pop Affected)	4.87	13.10	2.11e-05	151.82
Avg. Credit (% of GDP)	22.87	17.60	1.72	91.76
Annual Growth (%)	1.86	8.45	-62.37	118.24

Table 2.4: Contemporaneous effects of disasters on growth using the binary measure of disasters

	Dependent variable: Annual growth				
	(1)	(2)	(3)	(4)	(5)
Disaster	-0.9409*** (-2.86)	-1.6117*** (-2.78)	-1.4863*** (-2.64)	-1.7906*** (-2.92)	-0.5794 (-0.55)
Dis*Credit		0.0275** (2.35)		0.0293** (2.33)	0.0210* (1.74)
Credit		-0.0157* (-1.68)		-0.0097 (-1.16)	-0.0087 (-1.10)
Dis*AvgCred			0.0231* (1.89)		
Dis*Poor				0.3151 (0.53)	
Dis*AgriShare					-0.0346 (-0.65)
Obs.	4302	3895	3706	3442	3372
Countries	170	170	146	146	143
Adj. R-Sq.	0.0877	0.0809	0.1164	0.1075	0.1037

Note: Annual data 1979-2007, except where lost due to lags.

All models include a constant term, a lagged income term, country and year fixed effects.

Errors clustered at the country level. t-statistics in parenthesis.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2.5: Contemporaneous effects of disasters on growth using the continuous measure of disasters

	Dependent variable: Annual growth		
	(1) All	(2) Excl. top 1%	(3) Excl. top 5%
Disaster	-7.7526 (-1.53)	-14.3958** (-1.99)	-24.6804*** (-2.81)
Dis*Credit	0.1300 (1.00)	0.1647 (1.01)	0.4754*** (3.47)
Credit	-0.0060 (-0.77)	-0.0063 (-0.80)	-0.0089 (-1.09)
Obs.	3439	3425	3361
Countries	146	146	146
Adj. R-Sq.	0.1071	0.1099	0.1025

Note: Annual data 1979-2007, except where lost due to lags.

All models include a constant term, a lagged income term, country and year fixed effects.

Errors clustered at the country level. t-statistics in parenthesis.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2.6: Dynamics of disasters and growth: Cumulative lagged effects

	Dependent variable: Annual growth				
	(1) No Lags	(2) 1 Lag	(3) 3 Lags	(4) 5 Lags	(5) 10 Lags
Disaster	-1.5271** (-2.33)	-1.3418 (-1.58)	-3.4863** (-2.50)	-3.8557** (-2.11)	-5.6121** (-2.11)
Dis*Credit	0.0267** (2.07)	0.0303 (1.60)	0.0675** (2.27)	0.0799** (2.01)	0.1147* (1.94)
Obs.	3210	3179	3109	2818	2097
Countries	146	146	146	145	141
Adj. R-Sq.	0.1140	0.1100	0.1153	0.1042	0.1408

Note: Annual data 1979-2007, except where lost due to lags.

All models include a constant term, a lagged income term, country and year fixed effects.

The credit measure was entered as a separate regressor in each model.

Reported coefficients and t-stats are the summed contemporaneous and lagged effects.

Errors clustered at the country level. t-statistics in parenthesis.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2.7: Dynamics of disasters and growth: Including lags of growth

	Dependent variable: Annual growth				
	(1) No Lags	(2) 1 Lag	(3) 3 Lags	(4) 5 Lags	(5) 10 Lags
Disaster	-1.5271** (-2.33)	-1.2352 (-1.55)	-3.5255** (-2.58)	-3.9057** (-2.15)	-5.8917* (-1.87)
Dis*Credit	0.0267** (2.07)	0.0274 (1.54)	0.0668** (2.27)	0.0797** (2.01)	0.1144 (1.60)
Obs.	3210	3179	3109	2815	2094
Countries	146	146	146	145	141
Adj. R-Sq.	0.1140	0.1133	0.1201	0.1065	0.1625

Note: Annual data 1979-2007, except where lost due to lags.

All models include a constant term, a lagged income term, country and year fixed effects.

Lags of growth were included corresponding to the no. of lags of disasters in each model.

The credit measure was entered as a separate regressor in each model.

Reported coefficients and t-stats are the summed contemporaneous and lagged effects.

Errors clustered at the country level. t-statistics in parenthesis.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2.8: Dynamics of disasters and growth: Including agricultural dependence

	Dependent variable: Annual growth				
	(1)	(2)	(3)	(4)	(5)
	No Lags	1 Lag	3 Lags	5 Lags	10 Lags
Disaster	-0.4822 (-0.45)	-0.1754 (-0.16)	-2.0334 (-1.65)	-1.9622 (-1.47)	-3.5160* (-1.81)
Dis*Credit	0.0192* (1.70)	0.0228 (1.28)	0.06014** (2.11)	0.0710* (1.87)	0.1062* (1.93)
Dis*AgriSh.	-0.0374 (-0.66)	-0.0451 (-0.79)	-0.0609 (-1.02)	-0.0790 (-1.29)	-0.0810 (-1.23)
Obs.	3144	3114	3046	2761	2055
Countries	143	143	143	142	138
Adj. R-Sq.	0.1113	0.1079	0.1143	0.1058	0.1460

Note: Annual data 1979-2007, except where lost due to lags.
All models include a constant term, a lagged income term, country and year fixed effects.
The credit measure was entered as a separate regressor in each model.
Reported coefficients are the summed contemporaneous and lagged effects.
Errors clustered at the country level. t-statistics in parenthesis.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Chapter 3

The effects of natural disasters on human capital accumulation

3.1 Introduction

In this chapter I investigate the effects of natural disaster events on the accumulation of human capital, with a particular focus on the circumstances of low-income countries. Natural disasters represent transient shocks to the economy, and therefore in theory, should be relatively unimportant for the long-term process of economic development. However, in the previous chapter, I have shown that in the context of developing countries, with weak financial sector development, disaster recovery will be delayed by a lack of access to credit, resulting in persistent medium-term effects of disasters on economic growth.

Natural disasters frequently result in large-scale loss of life, injury and the spread of illness - alongside the displacement of populations, the disruption to everyday life and the welfare costs imposed by the associated destruction of physical assets. These humanitarian effects of natural disasters are suffered disproportion-

ately by poorer people and countries. Potentially, the disruption of human capital could represent an important channel of transmission from the transient shock of a disaster to long-term economic development.

Human capital accumulation has come to be seen as a crucial determinant of long-term growth potential (e.g. Barro, 1991). Quite apart from this indirect link from human capital to development (as proxied by economic growth), the accumulation of human capital - unlike the expansion of GDP - surely represents a development goal in itself. The term human capital generally refers to the health and education of a population. It thus forms two thirds of the UN's Human Development Index, which is made up of income per capita, life expectancy and education.

In spite of its potential significance, relatively few studies have attempted to test the effects of natural disasters on human capital accumulation at a macro level (i.e. using national level data). One exception to this is a recent paper by Crespo Cuaresma (2010), which finds evidence of a negative correlation between geological disasters and secondary school enrollment rates. At a micro level (using household level data and/or detailed case studies) there is a range of literature that examines the effects of shocks due to natural disaster events on household consumption, investment and human capital accumulation (e.g. Dercon, 2004; Jalan & Ravallion, 2001; Lokshin & Ravallion, 2000). With regard to human capital accumulation, a recent review of this micro literature is provided by Baez *et al.* (2010).

In general, the long-term economic effects of natural disasters are as yet not well understood (Cavallo & Noy, 2009). One of the few papers that attempts to quantify the long-term consequences of disasters on economic growth is a much-cited paper by Skidmore & Taya (2002). These authors find a positive correlation between disaster frequency and economic growth, arguing that this could be the result of disasters lowering the opportunity cost of investing in human capital (relative to investing in physical capital).¹ However, their findings have been questioned on methodological grounds (Raddatz, 2009). Their theory regard-

¹It is highly debatable to what extent the physical capital effects of disasters outweigh the human capital effects, as will become apparent from the discussion below.

ing the relative investment in human as opposed to physical capital remains an untested hypothesis. In this chapter, I set out to test the effects of disasters on human capital accumulation.

3.1.1 The humanitarian effects of natural disasters

Natural disaster events can have devastating impacts on the populations of affected regions. However, the economic consequences of humanitarian disasters are not clear *a priori*. It is not generally thought, for example, that changes in the absolute size of the population should affect the rate of economic growth. This relationship may become more complex if natural disasters affect certain age-groups disproportionately, thus altering the demographic profile of the population - something which has been shown to influence economic growth (Bloom *et al.* , 2001).

The human consequences of disasters may be significant for economic growth through their effects on human capital accumulation, which has come to be seen as a crucial determinant of long run development potential in the so-called new economic geography literature (Sachs *et al.* , 2001; Masters & McMillan, 2001), and in modern theories of economic growth (Mankiw *et al.* , 1992).

The accumulation of human capital is likely to be affected by extreme events in two ways; directly - through a combination of injury, illness and death - and indirectly, through the effects of these events on household income and time budgets. The direct effects are quite straightforward. Illness and injury associated with extreme events prevent children from attending school, while those killed by extreme events represent a lost investment in human capital. Furthermore, natural disaster events often lead to disease outbreaks, predominantly in poorer countries where infrastructure may be inadequate.

Hales *et al.* (2003) detail the potential impacts of extreme weather events (and other natural/humanitarian disasters) on the disease profile of the human population. In particular, extremes of both flooding and drought have been associated with increased incidences of malaria, outbreaks of various water-borne diseases (including cholera, typhoid and other diarrhoeal diseases) and rodent-

borne diseases such as plague, Lyme disease and hantavirus pulmonary syndrome (HPS).²

While disease epidemics are generally the result of a complex interaction between physical, ecological and social mechanisms, the trigger is often an extreme weather event, leading to; shortage or contamination of water supplies; malnutrition of the population (through reduced food supply) and population displacement; increased pressure on local infrastructure and health facilities; and in some cases improved breeding conditions for the vector organisms and intermediate hosts that carry disease (Hales *et al.* , 2003). The effects of disease on human capital accumulation are unsurprisingly profound, and include; missed school days due to illness, the loss of past investments through death, and in some cases permanently reduced cognitive ability as a result of contracting certain diseases.

In a recent study, Eppig *et al.* (2010) show a strong negative correlation between parasite prevalence and average national IQ scores. These authors argue that various diseases retard brain development due to the extra strain they place on the body's metabolic capacity. A similar view is put forward by Sachs & Malaney (2002a) in their review of the developmental effects of malaria.

The indirect impacts of disasters for human capital are again likely to be much more significant in poorer countries. By definition, natural disasters represent a negative wealth shock. Disasters also frequently affect the time available for labour force participation. For example, people's lives may be disrupted by damage to basic infrastructure and utilities, while family members may become ill, or get injured or killed by the event, reducing available time at the household level. Where people live close to subsistence, a negative shock to household income or a reduction of available time could have profound effects on household budget decisions - e.g. decisions regarding the education of children. It has

²There is also a significant literature on the mental health impacts of disasters, as reviewed in Norris *et al.* (2002). Various conditions such as post-traumatic stress disorder (PTSD), depression and anxiety are commonly found amongst populations that have experienced and survived disasters. The review by Norris *et al.* (2002) shows that the severity of mental health impacts is found to be higher for disasters occurring in developing as opposed to developed countries. However, the review also concludes that "man-made" disasters, especially mass violence events, tend to have a greater impact on mental health of the surviving population than "natural" disasters.

been shown that poorer households in developing countries often will be forced to withdraw children from school in response to a shock to household income (Jacoby & Skoufias, 1997). In such a scenario, children are effectively used as a form of “self-insurance” against income shocks. If households are unable to access credit (or formal insurance), drawing on child labour may represent one of the few available coping mechanisms during times of scarcity. In this way a transient shock due to the occurrence of a natural disaster might have a lasting legacy for economic development.

3.1.2 Human capital and credit access

It has often been shown that educational attainment depends, at least partially, on parental income. A range of studies based on US data are reviewed by Taubman (1989). A more recent discussion of the relationship between credit constraints and human capital is provided by Lochner & Monge-Naranjo (2011). While such a positive correlation could be explained by the consumption good interpretation of education, it may also be a result of liquidity constraints on investment in human capital. In the context of low-income countries, the liquidity constraint interpretation seems the more plausible, while supporting evidence is presented in Jacoby (1994) for Peruvian data.

Credit markets for investing in human capital are unlikely to function well, for a number of reasons (Loury, 1981; Becker & Tomes, 1979). Parents cannot constrain their children to repay debts incurred on their behalf; the likely returns to education are unknown, even to the borrower; while factors such as childhood nutrition and pre-school education are fundamentally income-constrained. Jacoby & Skoufias (1997) find that school attendance in rural Indian villages responds to income shocks, which they interpret as evidence of incomplete markets for investing in human capital. Poorer households are known to “self-insure” against income shocks by drawing on child labour in times of scarcity (Scoones & Chibudu, 1996). Further evidence of the link between income volatility and investment in human capital is presented in Flug *et al.* (1998). Thus, while disaster events may appear to represent merely transient shocks from an economic viewpoint, the long-term

developmental consequences of such events could be profound indeed, given their potential to constrain investments in human capital.

3.2 Modelling the human capital effects of disasters

In this section I present the theoretical framework for my analysis. A simple two-period model is used to demonstrate the effects of natural disasters on the optimal allocation of household time between labour force participation and human capital accumulation, as follows:³

Agents maximize utility

$$U = \ln(C_1) + B\ln(C_2) \quad (3.1)$$

subject to

$$C_1 = F(HK_1, L_1) - S_1 \quad (3.2)$$

and

$$C_2 = F(HK_2, L_2) + \frac{S_1}{R} \quad (3.3)$$

where periods are subscripted 1 and 2. The production function $F(\bullet, \bullet)$ is assumed to be at least twice continuously differentiable and exhibit constant returns to scale in its two arguments. B is the discount factor and R is the interest factor (i.e. one over one plus the interest rate). For the unconstrained

³The basic structure of the model follows Barry (1999) and is similar to that outlined in the previous chapter.

small open economy, the interest rate is an exogenous, risk-free world interest rate.

For simplicity, the accumulation of human capital is assumed to depend solely on time spent acquiring productive skills. Thus human capital accumulation is through foregone labour. Agents are endowed with a stock of productive skills in period one, which they supplement by spending time training during the first period.⁴

$$HK_2 = HK_1 + h \quad (3.4)$$

A further constraint on maximization behaviour is time. In period 1, agents must allocate their time between working and human capital accumulation. It is assumed that human capital must be accumulated one period in advance of use, and therefore no time is spent accumulating human capital in period 2. Available time in each period is normalized to unity.

$$T_1 = L_1 + h = 1 \quad (3.5)$$

$$T_2 = L_2 = 1 \quad (3.6)$$

Where L_i represents the fraction of time devoted to labour force participation in each period, and h the fraction of time devoted to human capital accumulation in period 1.

Thus, using equations (3.5) and (3.6) we can write HK_2 as follows:

⁴An alternative way of thinking about this trade off between labour force participation and human capital accumulation, is a parent's decision about how to divide their time between working and caring for or educating their children. This interpretation is similar in spirit to the idea of the "quantity-quality trade off" (see Becker *et al.* , 1990).

$$HK_2 = HK_1 + T_1 - L_1 \quad (3.7)$$

Replacing HK_2 in equation (3.3) with this new expression, we now have

$$C_2 = F[(HK_1 + T_1 - L_1), L_2] + \frac{S_1}{R} \quad (3.8)$$

The first-order conditions for the solution of the maximization problem are thus

$$C_2 = C_1 \left(\frac{B}{R} \right) \quad (3.9)$$

$$F_{HK2} = F_{L1}/R \quad (3.10)$$

Equations (3.9) and (3.10) represent the inter-temporal efficiency conditions for effective consumption and investment. Optimal investment in human capital involves equating the return on human capital (the marginal product of human capital in period 2, F_{HK2}) with the returns to labour force participation, scaled by the interest rate. Optimal consumption involves consumption smoothing according to (3.9).

Shocks that cause disruptions to people's lives and/or cause injury, illness or even death, can be modelled as a reduction in available time in period 1. From (3.9) above, we know that in equilibrium $C_2 = C_1(B/R)$. We can use (3.2) and (3.8) to rewrite this expression as follows:

$$\left(\frac{B}{R} \right) [F(HK_1, L_1 - S_1) - F[(HK_1 + T_1 - L_1), L_2] + \frac{S_1}{R}] = 0 \quad (3.11)$$

This expression (which we denote by Φ) allows us to exploit the implicit function theorem in solving the model. We need to verify first that $\Phi_{L1} \neq 0$ and that $\Phi_h \neq 0$. Recalling that $HK_2 = HK_1 + T_1 - L_1$ we have

$$\Phi_{L1} = (B/R)F_{L1} + F_{HK2} > 0 \quad (3.12)$$

Similarly, rewriting L_1 as $(T_1 - h)$ and HK_2 as $(HK_1 + h)$, we have

$$\Phi_h = -F_{L1}(B/R) - F_{HK2} < 0 \quad (3.13)$$

For a shock to available time (occurring in period 1), the comparative statics we are interested in are (dL_1/dT_1) and (dh/dT_1) . By the implicit function theorem

$$(dL_1/dT_1) = (-\Phi_{T1}/\Phi_{L1}) = ([F_{HK2} - (B/R)F_{L1}]/\Phi_{L1}) \quad (3.14)$$

Since we know that the denominator is positive, the sign of equation (3.14) depends on the relative magnitudes of F_{HK2} and F_{L1} .

Similarly,

$$(dh/dT_1) = (-\Phi_{T1}/\Phi_h) = ([F_{HK2} - (B/R)F_{L1}]/\Phi_h) \quad (3.15)$$

In this case the denominator is negative.

From the first-order condition for optimal ‘investment’ (i.e. optimal accumulation of human capital), we know that $F_{HK2} = F_{L1}/R$. Thus it must be that, in equilibrium, $F_{HK2} > F_{L1}(B/R)$, (given that $0 < B < 1$). The results of the implicit function theorem analysis therefore imply that

$$(dL_1/dT_1) > 0 \quad (3.16)$$

and

$$(dh/dT_1) < 0 \quad (3.17)$$

or in other words, as T_1 falls, the fraction of available time devoted to labour force participation (L_1) falls, while the fraction of available time devoted to human capital accumulation (h) rises (in order to maintain the optimal *level* of investment in human capital).

For the unconstrained economy, the reallocation of time following the shock in period 1 will serve to maintain the optimal level of investment in human capital. As available time shrinks in period 1 (as a consequence of the shock), unconstrained agents will devote a greater proportion of their time to human capital accumulation in order to maintain the optimal (equilibrium) investment level; i.e. in order to maintain $F_{HK2} = F_{L1}/R$.⁵ In this way, the shock is fully compensated for, in terms of its effects on human capital accumulation.

However, the shock to available time is not costless, even for the unconstrained economy. Combining (3.2), (3.8) and (3.9) we can write an equilibrium expression for C_1 as follows

$$C_1 = \frac{R}{(B+1)} \left\{ F[(HK_1 + T_1 - L_1), L_2] + \left(\frac{1}{R} \right) F(HK_1, L_1) \right\} \quad (3.18)$$

For a shock that reduces available time in period 1, totally differentiating this equation yields

$$\frac{dC_1}{dT_1} = \frac{R}{(B+1)} \left[F_{HK2} + \left(\frac{1}{R} \right) F_{L1} \right] > 0 \quad (3.19)$$

indicating, as one would expect, that such a shock will force a reduction in con-

⁵This assumes diminishing marginal returns to human capital investment.

sumption. By the first-order condition for optimal consumption (equation 9), second period consumption must also fall as follows:

$$\frac{dC_2}{dT_1} = \frac{B}{(B+1)} \left[F_{HK2} + \left(\frac{1}{R} \right) F_{L1} \right] > 0 \quad (3.20)$$

Thus, the shock to available time causes consumption to fall in each period, reducing lifetime welfare.⁶ For relatively poor households, a drop in consumption may involve the reduction of calorie intake leading to malnutrition, or the inability to afford medicines and basic health services. Thus, for households living close to subsistence, these welfare effects of the disaster shock will not only reduce utility in the short run (by forcing a reduction in consumption), but may also have longer-term effects on the productivity of the household, if a reduction in consumption leads to worse health outcomes.⁷

In a credit-constrained economy, with no access to world capital markets, the interest rate is no longer an exogenous world rate, but rather an endogenously determined rate (that serves to clear the goods market in each period). For a shock that reduces available resources in the economy (e.g. household time) in period 1, the interest rate will rise to preserve equilibrium. A higher interest rate means the interest factor, R , is smaller, and therefore implies a higher required rate of return on human capital investments (given $F_{HK2} = F_{L1}/R$ in equilibrium). Assuming diminishing marginal returns to human capital accumulation, a rising interest rate will imply a lower level of investment in human capital. Thus, the reallocation of time in period 1 following the shock, will not maintain investment in human capital at pre-shock levels in a credit-constrained economy.

To see this effect, we need to return to the results obtained above for (dL_1/dT_1) and (dh/dT_1) . The sign of these partial derivatives depends on the relative values of F_{HK2} and $F_{L1}(B/R)$. With a constant R , we know that $F_{HK2} > F_{L1}(B/R)$

⁶For a credit-constrained economy, optimal consumption smoothing may not be possible, with the result that the burden of these welfare effects would be absorbed primarily by reduced first period consumption.

⁷Zimmerman & Carter (2003) discuss the potential for consumption shocks to translate into productivity shocks for households living close to the subsistence threshold.

(from the first-order condition for optimal investment). However, if the interest rate rises in response to the shock, and thus the interest factor (R) falls, the magnitude of this inequality is diminished. The partial derivatives are thus necessarily smaller in magnitude, meaning that the compensating reallocation of time is dampened in the credit-constrained economy.

3.3 Empirical analysis

Based on the literature review of the humanitarian effects of natural disasters, we would expect that disasters would have significant direct (contemporaneous) effects on human capital accumulation. However, I have also shown - using evidence from the literature on human capital investment and some simple theoretical analysis - that disasters are likely to have additional indirect (dynamic or lagged) effects on households' ability to invest in human capital. In this section, I test these ideas on a panel of data covering 170 countries over the period 1980-2004.

3.3.1 Data

Data on natural disasters are obtained from EM-DAT, the international emergency events database maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the University of Louvain in Belgium. This dataset covers all major natural disaster events across 180 countries from 1960 to the present. Economic data are taken from the World Bank's World Development Indicators 2010. As a measure of the flow of investment in education, I use secondary school enrollment rates - defined as the ratio of total enrollment, regardless of age, to the population of the age group that officially corresponds to secondary level education in each country. According to the World Bank, "secondary education completes the provision of basic education ... and aims at laying the foundations

for lifelong learning and human development”.⁸ I also investigate the effects of disasters on various measures of health outcomes - life expectancy (aggregate, and separately for males and females), and maternal, infant and under-five mortality rates. Unfortunately the data on these human capital indicators are not available on an annual basis for most countries. Because of this data restriction, I decided to aggregate the available data into 5-year periods. The data sample covers the period 1980-2004, thus resulting in 5 periods of 5 years each.

I construct three measures of disasters, aggregated over the 5-year periods, for use in my analysis. It is standard in the literature on the economic effects of natural disasters to take the proportion of a country’s population affected by disasters as a measure of the disaster’s severity. This method avoids using the controversial economic damages data, and also makes sense in the present context, given the focus on the humanitarian effects of disasters.

In the previous chapter I constructed a measure of disaster severity using annual data as follows:

$$Disaster_{it} = \sum_j \frac{TotalAffected_{it,j}}{Population_{i,t-1}} \quad (3.21)$$

where j indexes the number of events recorded in country i in year t .⁹ I use this as the basis for the three measures of disasters included in my analysis here.

The first measure I construct is a count of the number of years (in each 5-year period) in which the above ratio exceeds 0.5 percent of the population. This measure is therefore restricted to be an integer between 0 and 5 in each country-period observation. The second measure of disaster severity that I construct is a simple sum of the above ratio over each 5-year period. Finally, I construct a binary measure of disaster severity that takes a 1 if the sum measure for the 5-year period exceeds 2.5 percent of the population, and a 0 otherwise.

I use the level of credit to the private sector as a proportion of GDP (as origi-

⁸See the World Bank’s online database of World Development Indicators: < data.worldbank.org > .

⁹The total number affected by a disaster includes those injured, made homeless or otherwise displaced by the event. The population from the previous period ($t-1$) is taken to avoid the denominator being dependent on the numerator in the equation for $Disaster_{it}$.

nally compiled by Levine *et al.* , 2000) as a proxy for financial sector development. The data for this series are taken from the World Bank's World Development Indicators.¹⁰ I am also interested in the role of aid flows, and their potential to mitigate the humanitarian effects of disasters. I use the net Official Development Assistance (in current US\$ per capita) series from the World Bank's World Development Indicators, as my measure of aid flows. Summary statistics for the key variables used in my analysis are included in table 3.5.

3.3.2 Empirical framework

In the empirical analysis, reported below, I run panel regressions of the following form

$$HK_{it} = \beta_0 + \beta_1 y_{it} + \beta_2 D_{it} + \beta_3 credit_{it} + \beta_4 ODA_{it} + \beta_5 D_{it} * X_{it} + \theta_i + \theta_t + \epsilon_{it} \quad (3.22)$$

where HK_{it} represents the relevant human capital measure in country i for period t . The term D_{it} represents the various measures of natural disasters described above. I use an interaction term $D_{it} * X_{it}$ - where X is either credit or aid flows, depending on the regression specification - in order to test directly the potentially mitigating influence of credit access or aid flows on the relationship between disasters and human capital.

In most of the reported regressions, I include income per capita in logs (y_{it}), credit and aid flows (ODA) as additional, separate control variables. To control for any omitted country-specific, time-invariant factors, I also include country fixed effects (θ_i) and cluster errors by country. I also include time fixed effects (θ_t) to control for trends in the data or shocks that affect all regions simultaneously. We would expect the period fixed effects to pick up the general trend towards higher educational attainment and better health outcomes over time, although this approach should also control for any common shocks occurring across countries in a given period, that are not otherwise controlled for in my regres-

¹⁰This data series is discussed in more detail in Chapter 2.

sions.¹¹

To test for the indirect (dynamic) effects of disasters on human capital accumulation - as discussed above - I run versions of the above regression with lags of the disaster term and the interaction term added. If the cumulative coefficients on the sum of the contemporaneous and lagged variables remains significant, we can interpret this as evidence that disasters have *persistent* effects on human capital accumulation. Indeed, my results show that the cumulative coefficients remain significant with two lags added, indicating persistence in the disaster effects on human capital. These results form the most important contribution of this chapter, as they indicate an indirect mechanism of effect from disasters to human capital, and potentially important long-term effects of disasters on development that would not be identified in more standard short-term analyses of disaster impacts.

3.3.3 Results

I present the results of my regression analysis in tables 3.2 - 3.13. While the results vary somewhat (in terms of significance) across the different model specifications, there appears to be sufficient evidence to support the notion that disasters have both direct and indirect effects on human capital. The direction of the effects is as expected and consistent across different model specifications (and measures of disasters), with disasters reducing school enrollment rates and life expectancy and raising mortality rates for mothers, infants and under-5s.

In general the magnitude (and significance) of the effects appears to be greater for poor countries than for the full sample of countries (the one exception being the contemporaneous effect of disasters on school enrollment - tables 2 and 3). Disasters also appear to have a stronger effect on life expectancy for females than

¹¹An alternative estimation strategy would be a differences-in-differences approach, although such an approach would require that the underlying trends in human capital, in the absence of disaster shocks, should be consistent across countries, which may not be plausible for such a large and diverse sample of countries. Future research could employ a differences-in-differences approach on a smaller number of countries that share similar attributes, or perhaps more profitably on a sub-national analysis that compares regions affected by disasters with those that are unaffected.

for males. This is true for both the contemporaneous effects and the lagged (indirect) effects. This finding is suggestive of a gender-based aspect to the impacts - perhaps reflecting greater *ex-ante* vulnerability of females, or indeed an imbalance in the allocation of post-disaster resources.

It is interesting to note that income measures appear to be important for health outcomes, whereas for school enrollment rates, credit access appears to matter more. For the contemporaneous results, we see evidence of this distinction in the coefficients on income per capita, ODA and the credit measure and also in the interaction terms between disasters and credit and between disasters and ODA. This relationship is also borne out in the dynamic or lagged analysis, which shows that disasters have persistent effects on human capital at up to 15 years after the event. These effects are mitigated, in the case of school enrollment rates, by access to credit, whereas aid flows appear to be effective in mitigating the longer-term effects of disasters on health outcomes.¹²

3.4 Discussion

The reported results show that disasters have important consequences for human capital accumulation. Human capital clearly represents a goal of development, in itself. But it is also a key ingredient in building sustainable economic development in poor countries. The direct effects of natural disasters on human capital are quite straightforward, resulting from a combination of injury, illness and death caused by the disaster. The direct (contemporaneous) results are therefore unsurprising, although such effects have rarely been demonstrated at a macro level in previous literature. The indirect effects - which operate through the effects of disasters on household time and budgeting decisions - have also been shown here to be substantial. Such effects, in the case of school enrollment rates, appear to be dependent on the ability of households to access finance in the immediate aftermath of a natural disaster. For the health outcomes, the indirect effects of

¹²For school enrollment rates, the interaction between disasters and ODA was not significant in the lagged regressions. Similarly, for the health outcomes, the interaction between disasters and credit access was not significant in the lagged regressions.

disasters appear to be mitigated by aid flows.

The dynamic results pick up on effects that would not otherwise be revealed in the analysis. The occurrence of a natural disaster might impact on the health and wellbeing of young children and infants (and on the financial circumstances of their families). Such effects (other than fatalities of course) might be considered transitory in nature. However, this is only the case provided the family has access to the finance necessary to seek medical treatment and pay for medicines (in the case of injury or illness) or to keep their children in school even in the face of a negative shock to household wealth (including the loss of household assets and income or a reduction in available time). If such finance is unavailable to the household at the time of the disaster, the transient shock may have long-lasting effects on the ability of the household to invest in education. Illness and malnutrition in early childhood have been shown to have dramatic long-term effects on human capital accumulation (e.g. Alderman *et al.* , 2006; Lozoff, 1989; McKay *et al.* , 1978), while a child that is withdrawn from school at primary level is unlikely to go on to secondary education. These effects would only show up in the secondary school enrollment data once the child has reached the age at which secondary school attendance normally begins. This might be some 10 or more years after the disaster - thus justifying the inclusion of two lags in the dynamic analysis.¹³ Analyses that focus on the short-term impacts of disasters are likely to miss the potentially important indirect human capital effects identified here.

3.5 Conclusions

While it is obvious - and well documented - that natural disasters can have large-scale humanitarian effects, the implications of such effects for the accumulation of human capital have rarely been demonstrated at a macro level. It has also been pointed out recently that our understanding of the long-term economic effects of natural disasters remains relatively limited. This chapter contributes to the

¹³The dynamic analysis covers a total period of between 10 and 15 years after the disaster, given that the disaster could have occurred at any stage during the contemporaneous 5-year period, and the analysis includes a further two 5-year periods.

literature by demonstrating both a direct (contemporaneous) and an indirect (dynamic) effect of disasters on human capital accumulation at a macro level. The dynamic effect is particularly noteworthy, as it indicates the potential for disasters to have long-term impacts on the development prospects of affected regions - effects which would not have been identified in previous literature that focussed on the short-term impacts of disasters.

The indirect effects appear to be dependent on the availability of credit (in the case of school enrollment rates), or on aid flows (in the case of health outcomes), in the aftermath of a disaster occurrence. This finding suggests that financing schemes should be viewed as an important policy response to disaster occurrences - and a crucial step in the long-term recovery process, alongside investment in infrastructure and physical reconstruction. The findings reported here are therefore of interest to both development specialists and policymakers alike. While aid flows may be sufficient to mitigate the health impacts of disasters, it appears that other measures - such as making finance or credit available to households, would be required to mitigate the longer-term impacts of disasters on educational attainment in affected regions.

Potential extensions of this research include a more direct investigation of household time allocation in the aftermath of disasters - possibly using survey data - and studies that explore the potential for financing schemes (micro-finance, weather-indexed insurance etc.) to ameliorate the human capital effects of disasters identified in this chapter.

Table 3.1: Summary statistics for key variables

Variable	Mean	Std. Dev.	Min.	Max.
GDP (per capita)	8,873	10,358	280	78,798
Avg. Credit (% of GDP)	38.09	36.13	0	218.19
Net ODA (US\$ per capita)	58.84	88.60	-3.06	1,024.38
<u>Human Capital</u>				
School enrollment (% of pop.)	58.35	32.75	2.40	154.75
Life expectancy (years)	64.13	10.49	28.87	81.57
Maternal mortality (per 100,000 births)	302.12	377.39	2	1,800
Infant mortality (per 1,000 live births)	50.49	39.40	2.6	176.76
Under-5 mortality (per 1,000)	74.36	67.18	3.46	314.88
<u>Disasters</u>				
Count measure	0.83	1.17	0	5
Sum measure (% of Pop. Affected)	8.23	19.88	0	176.26
Binary measure	0.32	0.47	0	1

Table 3.2: Disasters and school enrollment: Full sample, contemporaneous effect

	Dependent variable: School enrollment rates								
	Binary Measure			Sum Measure			Count Measure		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Disasters	-2.1234** (-2.30)	-2.6322** (-2.13)	-1.0744 (-0.88)	-4.4819 (-1.43)	-3.8846 (-0.82)	-0.5930 (-0.13)	-1.0113** (-2.01)	-1.4061** (-2.16)	-0.4628 (-0.87)
GDP (log per capita)	5.4592 (1.61)	5.4567 (1.60)	5.5044 (1.63)	5.4502 (1.62)	5.4481 (1.62)	5.7104* (1.67)	5.4396 (1.62)	5.5615 (1.63)	5.7326* (1.68)
Credit	0.1178** (2.17)	0.1170** (2.15)	0.1350** (2.30)	0.1174** (2.10)	0.1172** (2.10)	0.1306** (2.15)	0.1165** (2.16)	0.1145** (2.12)	0.1374** (2.33)
ODA (per capita)	-0.0228 (-1.10)	-0.0248 (-1.16)	-0.0231 (-1.13)	-0.0226 (-1.08)	-0.0224 (-1.07)	-0.0223 (-1.07)	-0.0211 (-1.01)	-0.0246 (-1.14)	-0.0213 (-1.02)
Disasters*ODA		0.0091 (0.58)			-0.0086 (-0.16)			0.0080 (1.04)	
Disasters*Credit			-0.0395 (-0.97)			-0.1507 (-1.08)			-0.0173 (-1.10)
Obs.	534	534	534	534	534	534	534	534	534
Countries	135	135	135	135	135	135	135	135	135
Adj. R-Squared	0.5385	0.5381	0.5389	0.5351	0.5342	0.5358	0.5382	0.5387	0.5390

Note: Data in 5-year periods, from 1980-2004. All models include a constant term, and country and period fixed effects.
 ODA is net Official Development Assistance (in current US\$ per capita). Errors clustered at the country level.
 t-statistics in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3.3: Disasters and school enrollment: Poor countries only, contemporaneous effect

	Dependent variable: School enrollment rates								
	Binary Measure			Sum Measure			Count Measure		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Disasters	-1.4830 (-1.53)	-2.1345 (-1.48)	-0.6790 (-0.47)	-5.1625 (-1.47)	-5.8843 (-1.11)	1.4181 (0.27)	-0.9688* (-1.74)	-1.3304* (-1.74)	-0.0929 (-0.18)
GDP (log per capita)	6.4561 (1.63)	6.3843 (1.60)	6.6254* (1.68)	6.3102 (1.61)	6.3089 (1.60)	6.9823* (1.74)	6.5033 (1.65)	6.5654 (1.64)	7.1746* (1.79)
Credit	0.2219*** (3.43)	0.2216*** (3.44)	0.2494*** (3.07)	0.2269*** (3.54)	0.2277*** (3.57)	0.2773*** (4.02)	0.2250*** (3.59)	0.2257*** (3.62)	0.2965*** (4.20)
ODA (per capita)	-0.0016 (-0.05)	-0.0069 (-0.21)	-0.0013 (-0.04)	-0.0016 (-0.05)	-0.0019 (-0.06)	-0.0019 (-0.06)	0.0004 (0.01)	-0.0061 (-0.19)	-0.0014 (-0.04)
Disasters*ODA		0.0107 (0.61)			0.0099 (0.16)			0.0068 (0.84)	
Disasters*Credit			-0.0383 (-0.55)			-0.2885 (-1.65)			-0.0314* (-1.94)
Obs.	336	336	336	336	336	336	336	336	336
Countries	85	85	85	85	85	85	85	85	85
Adj. R-Squared	0.5288	0.5282	0.5284	0.5305	0.5292	0.5355	0.5317	0.5318	0.5372

Note: Data in 5-year periods, from 1980-2004. All models include a constant term, and country and period fixed effects.

ODA is net Official Development Assistance (in current US\$ per capita). Errors clustered at the country level.

t-statistics in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3.4: Dynamic effects of disasters on school enrollment: Full sample

	Dependent variable: School enrollment rates		
	<u>Count measure</u>	<u>Sum measure</u>	<u>Binary measure</u>
	(1)	(2)	(3)
Disaster	-3.9813*** (-2.77)	-20.9473 (-1.48)	-5.1806* (-1.76)
Disaster*Credit	0.04878** (2.23)	0.4519 (1.64)	0.0990 (1.42)
Obs.	303	303	303
Countries	123	123	123
Adj. R-Squared	0.6060	0.5888	0.5964

Note: Data in 5-year periods, from 1980-2004 (except where lost due to lags).
The reported coefficients represent the cumulative effect over 3 periods
i.e. the cumulative effect at up to 15 years after the disaster event(s).
The associated t-statistics are calculated in Stata using the *lincom* command.
All models include a constant term, and country and period fixed effects.
Credit, income and ODA were entered as separate regressors in each model.
Errors clustered at the country level.
t-statistics in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3.5: Dynamic effects of disasters on school enrollment: Poor countries only

	Dependent variable: School enrollment rates		
	<u>Count measure</u>	<u>Sum measure</u>	<u>Binary measure</u>
	(1)	(2)	(3)
Disaster	-4.6996*** (-2.77)	-39.1462*** (-2.82)	-4.0565 (-1.42)
Disaster*Credit	0.0601** (2.65)	0.8374*** (2.90)	0.1521** (2.07)
Obs.	191	191	191
Countries	77	77	77
Adj. R-Squared	0.6303	0.6122	0.6007

Note: Data in 5-year periods, from 1980-2004 (except where lost due to lags).

The reported coefficients represent the cumulative effect over 3 periods

i.e. the cumulative effect at up to 15 years after the disaster event(s).

The associated t-statistics are calculated in Stata using the *lincom* command.

All models include a constant term, and country and period fixed effects.

Credit, income and ODA were entered as separate regressors in each model.

Errors clustered at the country level.

t-statistics in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3.6: Disasters and life expectancy: Full sample

Dependent Variable:	Life Exp.			Life Exp. Males			Life Exp. Females		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Disasters	-1.1487 (-1.19)	-2.8751* (-1.74)	0.0121 (0.01)	-0.8719 (-0.87)	-2.2903 (-1.26)	0.2639 (0.15)	-1.4394 (-1.47)	-3.4892** (-2.16)	-0.2524 (-0.13)
GDP (log per capita)	2.2585*** (2.70)	2.2558*** (2.69)	2.3047*** (2.75)	2.0978*** (2.62)	2.0956** (2.61)	2.1430*** (2.66)	2.4272*** (2.73)	2.4240*** (2.72)	2.4744*** (2.77)
Credit	0.0051 (0.45)	0.0057 (0.51)	0.0090 (0.80)	0.0010 (0.09)	0.0015 (0.13)	0.0049 (0.43)	0.0094 (0.81)	0.0101 (0.88)	0.0134 (1.15)
ODA (per capita)	0.0057 (1.29)	0.0047 (1.09)	0.0057 (1.29)	0.0047 (1.10)	0.0039 (0.92)	0.0047 (1.10)	0.0068 (1.44)	0.0056 (1.23)	0.0068 (1.45)
Disasters*ODA		0.0168* (1.73)			0.0138 (1.38)			0.0200** (1.98)	
Disasters*Credit			-0.0413 (-0.89)			-0.0404 (-0.97)			-0.0422 (-0.81)
Obs.	610	610	610	610	610	610	610	610	610
Countries	141	141	141	141	141	141	141	141	141
Adj. R-Squared	0.3474	0.3514	0.3478	0.3530	0.3554	0.3534	0.3243	0.3300	0.3246

Note: Data in 5-year periods, from 1980-2004. Disasters variable is the sum measure, as defined in the text.

All models include a constant term, and country and period fixed effects.

ODA is net Official Development Assistance (in current US\$ per capita). Errors clustered at the country level.

t-statistics in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3.7: Disasters and life expectancy: Poor countries only

Dependent Var:	Life Exp			Life Exp Males			Life Exp Females		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Disasters	-2.4115** (-2.05)	-5.7556*** (-3.28)	-1.0533 (-0.52)	-2.3175** (-2.14)	-5.5446*** (-3.50)	-1.1654 (-0.63)	-2.5101* (-1.96)	-5.9770*** (-3.06)	-0.9357 (-0.42)
GDP (log per capita)	2.7892*** (2.81)	2.7748*** (2.83)	2.8776*** (2.86)	2.4858*** (2.68)	2.4719*** (2.71)	2.5608*** (2.73)	3.1078*** (2.89)	3.0929*** (2.92)	3.2103*** (2.96)
Credit	0.0287 (1.56)	0.0319* (1.84)	0.0391* (1.96)	0.0223 (1.28)	0.0253 (1.56)	0.0311 (1.65)	0.0355* (1.81)	0.0388** (2.09)	0.0475** (2.23)
ODA (per capita)	0.0145 (1.33)	0.0141 (1.33)	0.0141 (1.29)	0.0115 (1.11)	0.0112 (1.11)	0.0112 (1.09)	0.0176 (1.51)	0.0172 (1.53)	0.0172 (1.48)
Disasters*ODA		0.0377** (2.48)			0.0364** (2.61)			0.0391** (2.36)	
Disasters*Credit			-0.0558 (-1.08)			-0.0473 (-0.99)			-0.0647 (-1.16)
Obs.	378	378	378	378	378	378	378	378	378
Countries	86	86	86	86	86	86	86	86	86
Adj. R-Squared	0.2817	0.2976	0.2818	0.3042	0.3206	0.3040	0.2595	0.2746	0.2600

Note: Data in 5-year periods, from 1980-2004. Disasters variable is the sum measure, as defined in the text.

All models include a constant term, and country and period fixed effects.

ODA is net Official Development Assistance (in current US\$ per capita). Errors clustered at the country level.

t-statistics in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3.8: Disasters and other health outcomes: Full sample

Dependent Var:	Maternal Mortality			Infant Mortality			Under-5 Mortality		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Disasters	56.5553 (1.45)	64.8993 (1.06)	40.2811 (0.56)	0.4461 (0.16)	6.7580* (1.69)	-1.7091 (-0.33)	4.9386 (1.00)	17.4034** (2.50)	1.5862 (0.17)
GDP (log per capita)	-168.2328*** (-4.68)	-167.8060*** (-4.63)	-168.9309*** (-4.72)	-3.4200 (-1.21)	-3.4211 (-1.20)	-3.5081 (-1.22)	-3.3203 (-0.67)	-3.3224 (-0.67)	-3.4574 (-0.70)
Credit	0.2650 (0.68)	0.2678 (0.68)	0.1898 (0.50)	0.0509 (1.39)	0.0487 (1.34)	0.0435 (1.11)	0.1170* (1.82)	0.1126* (1.77)	0.1055 (1.55)
ODA (per capita)	-0.3375 (-1.56)	-0.3281 (-1.48)	-0.3404 (-1.57)	-0.0279** (-2.08)	-0.0242* (-1.85)	-0.0279** (-2.08)	-0.0496** (-2.21)	-0.0424* (-1.93)	-0.0496** (-2.21)
Disasters*ODA		-0.1448 (-0.24)			-0.0611*** (-2.63)			-0.1206*** (-2.94)	
Disasters*Credit			0.6488 (0.22)			0.0772 (0.59)			0.1201 (0.52)
Obs.	361	361	361	601	601	601	601	601	601
Countries	127	127	127	139	139	139	139	139	139
Adj. R-Squared	0.3114	0.3095	0.3098	0.6448	0.6487	0.6445	0.5875	0.5932	0.5871

Note: Data in 5-year periods, from 1980-2004. Disasters variable is the sum measure, as defined in the text.

All models include a constant term, and country and period fixed effects.

ODA is net Official Development Assistance (in current US\$ per capita). Errors clustered at the country level.

t-statistics in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3.9: Disasters and other health outcomes: Poor countries only

Dependent Var:	Maternal Mortality			Infant Mortality			Under-5 Mortality		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Disasters	63.5891 (1.43)	63.5240 (0.85)	108.5087 (1.19)	3.2987 (0.92)	12.7031*** (2.68)	-4.6392 (-0.73)	9.6345 (1.48)	28.2060*** (3.54)	-2.4476 (-0.22)
GDP (log per capita)	-182.8244*** (-4.71)	-182.8287*** (-4.63)	-179.1122*** (-4.59)	-6.5798* (-1.87)	-6.5498* (-1.87)	-7.1021** (-1.99)	-7.8883 (-1.35)	-7.8289 (-1.34)	-8.6832 (-1.46)
Credit	-0.4248 (-0.69)	-0.4248 (-0.69)	-0.0954 (-0.12)	-0.0060 (-0.10)	-0.0152 (-0.27)	-0.0667 (-0.88)	0.0660 (0.63)	0.0477 (0.47)	-0.0265 (-0.20)
ODA (per capita)	-0.5229 (-1.12)	-0.5229 (-1.11)	-0.5117 (-1.09)	-0.0363 (-1.16)	-0.0354 (-1.13)	-0.0344 (-1.11)	-0.0533 (-0.99)	-0.0516 (-0.96)	-0.0505 (-0.94)
Disasters*ODA		0.0011 (0.00)			-0.1062** (-2.54)			-0.2098*** (-3.05)	
Disasters*Credit			-2.0467 (-0.49)			0.3259* (1.77)			0.4961 (1.63)
Obs.	230	230	230	377	377	377	377	377	377
Countries	79	79	79	86	86	86	86	86	86
Adj. R-Squared	0.3870	0.3842	0.3862	0.6428	0.6507	0.6463	0.6021	0.6127	0.6045

Note: Data in 5-year periods, from 1980-2004. Disasters variable is the sum measure, as defined in the text.

All models include a constant term, and country and period fixed effects.

ODA is net Official Development Assistance (in current US\$ per capita). Errors clustered at the country level.

t-statistics in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3.10: Dynamic effects of disasters on life expectancy: Full sample

Dependent variable:	Life Exp.			Life Exp. Males			Life Exp. Females		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Disaster measure:	Sum	Binary	Count	Sum	Binary	Count	Sum	Binary	Count
Disaster	-8.3757 (-1.58)	-1.8191 (-1.46)	-0.9077 (-1.66)	-7.0211 (-1.38)	-1.3859 (-1.18)	-0.7514 (-1.52)	-9.7980* (-1.75)	-2.2741* (-1.70)	-1.0718* (-1.75)
Disaster*ODA	0.0548 (1.26)	0.0248** (2.00)	0.0097** (2.09)	0.0475 (1.18)	0.0200* (1.78)	0.0076* (1.80)	0.0625 (1.32)	0.0299** (2.17)	0.0120** (2.29)
Obs.	370	370	370	370	370	370	370	370	370
Countries	139	139	139	139	139	139	139	139	139
Adj. R-Squared	0.2705	0.2731	0.2672	0.3066	0.3083	0.3024	0.2349	0.2388	0.2329

Note: Data in 5-year periods, from 1980-2004 (except where lost due to lags).

The reported coefficients represent the cumulative effect over 3 periods, i.e. up to 15 years after the disaster event(s).

The associated t-statistics are calculated in Stata using the *lincom* command.

All models include a constant term, and country and period fixed effects.

Credit, income and ODA were entered as separate regressors in each model. Errors clustered at the country level.

t-statistics in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3.11: Dynamic effects of disasters on life expectancy: Poor countries only

Dependent variable:	Life Exp.			Life Exp. Males			Life Exp. Females		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Disaster measure:	Sum	Binary	Count	Sum	Binary	Count	Sum	Binary	Count
Disaster	-14.2583** (-2.25)	-2.6817 (-1.56)	-1.1909 (-1.58)	-13.0684** (-2.23)	-2.1731 (-1.34)	-1.0739 (-1.58)	-15.5076** (-2.25)	-3.2156* (-1.75)	-1.3137 (-1.58)
Disaster*ODA	0.1068* (1.85)	0.0357** (2.16)	0.0145** (2.46)	0.1006* (1.93)	0.0303** (2.02)	0.0121** (2.26)	0.1134* (1.77)	0.0414** (2.25)	0.0170** (2.58)
Obs.	234	234	234	234	234	234	234	234	234
Countries	84	84	84	84	84	84	84	84	84
Adj. R-Squared	0.2689	0.2684	0.2560	0.2994	0.2947	0.2836	0.2407	0.2449	0.2310

Note: Data in 5-year periods, from 1980-2004 (except where lost due to lags).

The reported coefficients represent the cumulative effect over 3 periods, i.e. up to 15 years after the disaster event(s).

The associated t-statistics are calculated in Stata using the *lincom* command.

All models include a constant term, and country and period fixed effects.

Credit, income and ODA were entered as separate regressors in each model. Errors clustered at the country level.

t-statistics in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3.12: Dynamic effects of disasters on other health outcomes: Full sample

Dependent variable:	Maternal Mortality			Infant Mortality			Under-5 Mortality		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Disaster measure:	Sum	Binary	Count	Sum	Binary	Count	Sum	Binary	Count
Disaster	516.1516*** (3.69)	53.0693 (1.33)	30.8626 (1.57)	19.4365 (1.65)	-1.0457 (-0.35)	-0.0035 (-0.00)	45.8470** (2.18)	-1.6554 (-0.26)	0.3777 (0.15)
Disaster*ODA	-3.3178*** (-2.78)	-0.1339 (-0.31)	-0.1593 (-0.80)	-0.1991** (-2.25)	0.0265 (-0.97)	-0.0083 (-0.76)	-0.4140*** (-2.72)	-0.0458 (-0.89)	-0.0187 (-0.92)
Obs.	337	337	337	366	366	366	366	366	366
Countries	126	126	126	137	137	137	137	137	137
Adj. R-Squared	0.4302	0.3826	0.3855	0.6337	0.6206	0.6156	0.5527	0.5346	0.5348

Note: Data in 5-year periods, from 1980-2004 (except where lost due to lags).

The reported coefficients represent the cumulative effect over 3 periods, i.e. up to 15 years after the disaster event(s).

The associated t-statistics are calculated in Stata using the *lincom* command.

All models include a constant term, and country and period fixed effects.

Credit, income and ODA were entered as separate regressors in each model. Errors clustered at the country level.

t-statistics in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3.13: Dynamic effects of disasters on other health outcomes: Poor countries only

Dependent variable:	Maternal Mortality			Infant Mortality			Under-5 Mortality		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Disaster measure:	Sum	Binary	Count	Sum	Binary	Count	Sum	Binary	Count
Disaster	672.9451*** (4.51)	71.4774 (1.20)	53.8350** (2.09)	33.6356** (2.60)	-1.2251 (-0.30)	1.8232 (0.98)	71.5468*** (3.04)	-1.0907 (-0.13)	3.8738 (1.10)
Disaster*ODA	-4.4932** (-2.61)	0.0026 (0.00)	-0.1534 (-0.51)	-0.2903** (-0.47)	-0.0179 (-0.97)	-0.0128 (-0.88)	-0.5945*** (-2.72)	-0.0378 (-0.50)	-0.0262 (-0.93)
Obs.	218	218	218	234	234	234	234	234	234
Countries	78	78	78	84	84	84	84	84	84
Adj. R-Squared	0.5093	0.4543	0.3855	0.6715	0.6492	0.6390	0.6064	0.5761	0.5733

Note: Data in 5-year periods, from 1980-2004 (except where lost due to lags).
The reported coefficients represent the cumulative effect over 3 periods, i.e. up to 15 years after the disaster event(s).
The associated t-statistics are calculated in Stata using the *lincom* command.
All models include a constant term, and country and period fixed effects.
Credit, income and ODA were entered as separate regressors in each model. Errors clustered at the country level.
t-statistics in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Chapter 4

Geography and institutions: On the origins of comparative development

4.1 Introduction

For some time now, the debate within the macroeconomic literature on the *fundamental* sources of comparative economic development has been polarized into essentially two camps; on one side are those who argue in favour of geography-based theories of development, and on the other, are advocates of institutions-based explanations. A particularly well known and frequently cited contribution to the latter camp is Acemoglu *et al.* (2001) - henceforth AJR. The essential take-home message from that paper is that the income gap between rich and poor countries is primarily attributable to differences in their economic institutions (as proxied by security of property rights). AJR's results have also been

used to argue that geography (as proxied by latitude) has no direct effect on income, once institutions are ‘properly controlled for’:

Without considering the role of economic institutions, one would find a spurious relationship between latitude and income per capita. However, once economic institutions are properly controlled for, these relationships go away and there appears to be no causal effect of geography on prosperity today (though geography may have been important historically in shaping economic institutions).

- Acemoglu (2008, p.162)¹

The AJR results - along with other contributions to the ‘institutionalist’ camp - have been criticized on a number of grounds. For example, institutions are difficult to define and measure empirically and are almost certainly endogenous with respect to long-term economic development. Was it purely by chance that some societies developed better economic institutions than others? Certainly it is plausible that more economically advanced societies develop better economic institutions - for example, as a result of the demand for greater rights from an emerging merchant or entrepreneurial middle class, as occurred in many European city-states during the Middle Ages. It may also be that some third factor gave particular regions or societies an advantage both in economic development and in the formation of ‘good’ institutions.

To overcome this endogeneity problem, AJR employ the instrumental variable approach, using *settler mortality* as their instrument for institutional formation. The validity of this instrument might be questioned on the grounds that settler mortality is a function of the local disease environment, which itself is likely to have a direct effect on economic development. However, AJR insist that their instrument is not directly related to income. Even accepting the validity of the instrument, institutional quality in the AJR setup is determined - at least originally - by a factor (settler mortality) which itself is a function of geography, in the form of climatic conditions, which determine the local disease environment. Thus,

¹Quote and page number refer to a preliminary draft of the book manuscript, Version 2.2, October 2007.

this version of the long-term economic development story still relies on geography as the *fundamental source of institutional quality*, which in turn determines (modern) comparative economic development. Other critics of the ‘institutionalist’ literature have (rightly) pointed out that latitude is at best a proxy for some other factor, e.g. climate, which may be causally related to income, while latitude itself has no plausible causal relationship with income.

Leaving aside these - by now familiar - arguments, a more fundamental weakness in the analysis on both sides of this debate relates to the fact that few, if any, authors have taken account of the bi-modality of the global income distribution in their analysis. The bi-modality of global income was originally identified by Quah (1996, 1997) and since confirmed by, for example, Bloom *et al.* (2003). In the next chapter, I also demonstrate the superior fit of a two regime model on country level income per capita data. Figure 4.1 illustrates the bi-modality of the income data.² The graph displays a classic bi-modal pattern, with a large proportion of observations clustered at income levels below \$10,000 per capita (PPP), and a significant minority clustered at a higher income level between \$20,000 and \$30,000.

A bi-modal distribution indicates that observations are clustered around two distinct equilibria, possibly as a result of more than one data generating process. In the present context, this may correspond to distinct growth regimes across rich and poor countries. Numerous modern theories of economic growth that include various forms of poverty traps or non-convexities would predict just such a pattern. With this in mind, it is likely that the factors that determine income are diverse across the two growth regimes. Failing to take account of such bi-modality in the underlying distribution of the dependent variable can therefore skew regression results and obscure the true effects of the explanatory variables, which may be distinct across the two regimes (as demonstrated by Conway & Deb, 2005). A finite mixture model is used to identify exactly these kinds of non-uniform relationships.

²The graph is based on income per capita data (1995, PPP) from the Penn World Tables (PWT 7.0) and includes all countries for which these data were available (188 observations).

In the remainder of this chapter, I replicate the AJR findings and develop additional analysis aimed at identifying the effect on their results of accounting for the bi-modality of global income. For simplicity of exposition, I focus on AJR's main specification, which involves regressions of log income per capita (in 1995, PPP) on the instrumented institutions variable and latitude. I use AJR's original data - obtained directly from Daron Acemoglu's website - and concentrate on their 'base sample' of 64 countries.³

4.2 A first look: Analysis of sub-samples

Columns 1 and 2 of Table 4.1 replicate the main finding from AJR; in a standard OLS regression, both the quality of institutions (protection against expropriation risk) and latitude are significant predictors of income. However, once institutions are 'properly' controlled for, in a 2SLS regression (with settler mortality as the instrument for institutions), the coefficient on latitude is no longer significant. This finding may not represent the full picture, however. If the global income distribution is bi-modal, as suggested by Figure 4.1, then treating income observations as being drawn from a single distribution (as these regressions implicitly assume) may obscure the true relationship between the explanatory variables and income.

As a first, rudimentary check on this hypothesis, I simply split the AJR sample in two by median income and repeat the 2SLS regression on each of the sub-samples (results in columns 3 and 4 of Table 4.1). While the results remain fairly similar for the 'rich' country sub-sample, the standard errors become very large in the 'poor' country sub-sample, with the result that neither explanatory variable is significant in this regression (column 4). One possible concern is that the loss of significance here is simply a result of the relatively small sample size - particularly once the sample has been split in two. As a check on this, I repeat the sub-sample regressions using the bootstrap method to calculate standard errors

³To be precise, the dataset that I use in the remainder of this chapter is labelled 'maketable4' on Acemoglu's website.

(with 1,000 replications). The results are reported in columns 5 and 6. Although the coefficient on the institutions variable remains (marginally) significant for the ‘rich’ sub-sample, the standard errors are extremely high for the ‘poor’ sub-sample. It appears that the included independent variables are unable to explain the variation in income levels within the lower half of the income distribution - at least for this sample of countries (i.e. the 64 countries in AJR’s base sample).

In an attempt to identify the source of the very large standard errors in the bootstrap regressions, I use two approaches, as follows. First, I run the first stage of the 2SLS regression (i.e. regressing the institutions variable on settler mortality and latitude to generate the predicted values used in the second stage regression) and calculate *dfbeta* values in an attempt to identify any particularly influential observations. The standard threshold for an observation to be considered ‘influential’ is a *dfbeta* value (in absolute terms) $> (2/\sqrt{n})$. With $n = 64$, we have a threshold of around 0.25. Four countries have *dfbeta* values exceeding that threshold: Gambia (0.83), Singapore (-0.59), Mali (-0.30) and Australia (-0.25).

Column 1 of Table 4.2 replicates column 2 of Table 4.1, but with bootstrapped standard errors. We can see that even using the full sample, the coefficient on the institutions variable loses significance when estimating standard errors with the bootstrap method. In column 2, I exclude the most obviously ‘influential’ observations - i.e. Gambia and Singapore. This time, the coefficient on institutions is significant, using the bootstrap method for calculating standard errors. However, in column 3, where I also exclude Mali and Australia from the sample, the bootstrapped standard errors balloon to very large values once again. It appears that the results are quite sensitive to the countries included in the estimation sample.

As a further check on the source of the loss of significance in the bootstrapped estimates, I saved all 1,000 replications of the 2SLS regression (based on the full 64 country sample) and identified which iterations were generating the most extreme coefficient values, to see if there was any pattern in terms of the countries sampled in those iterations.⁴ I found that the most extreme coefficient estimates were typically generated from samples that excluded most (or all) of the following

⁴Recall that the bootstrap method selects a random sample of size n , with replacement, from the original data. This means that some observations (countries in this case) will occur multiple times in a given bootstrap sample, and others not at all.

countries: Malaysia, Singapore, Australia, New Zealand, Hong Kong and Mali. This suggests that when some (or all) of these countries are excluded, AJR's 2SLS approach cannot estimate meaningful relationships between institutions (instrumented by settler mortality) or latitude and income for the remaining sample of countries. Indeed when I exclude these six countries from the sample and run a straightforward 2SLS (without bootstrapping the standard errors), I find that settler mortality is no longer a significant predictor of institutions for the remaining 58 countries (in the first stage regression) and the predicted institutions variable is no longer significant in the second stage regression of income per capita.

One could easily think of reasonable arguments to explain why these countries might be outliers in terms of their economic development (or more specifically the relationship between institutions or latitude and income). Moreover, it is interesting to note that Australia and New Zealand have the joint lowest value for log settler mortality (2.15) in the sample of 64 countries, while Mali has the single highest value (7.99).

The above argument is not to suggest that the observed relationship between institutions and income in AJR is spurious, but rather that this relationship may hold for only a sub-sample of countries - as suggested by the bi-modality of the global income distribution. To explore this possibility more formally, I use a finite mixture model (FMM) approach - see Section 4.3 below and the results presented in Table 4.4. First, I continue to explore how sample selection influences the AJR results.

In Table 4.3 I replicate AJR's Table 4, but with a couple of notable innovations. The odd numbered columns in Table 4.3 reproduce the results in Table 4 of AJR, while the even numbered columns repeat the analysis using bootstrapped standard errors. It is notable that the institutions variable loses significance in each case when bootstrapped standard errors are implemented. This suggests a lack of robustness in the AJR findings. The one exception to this pattern is the sub-sample that excludes African countries (columns 5 and 6). I also include an additional sub-sample, which was not included in AJR's Table 4, comprising only African countries. Interestingly, the institutions variable is not significant in either the standard 2SLS regression or the bootstrapped version, for this sub-sample

(columns 9 and 10). The settler mortality instrument is also not a significant predictor of the institutions variable for the ‘Africa only’ sub-sample. It seems that the AJR approach cannot explain variations in institutional quality or variations in income within Africa (as noted by AJR - see their footnote 21, p.1387). This may also explain why the instrument loses some significance for the regression that includes continent dummies (column 7).

4.3 Comparing 2SLS and FMM approaches

AJR argue that geography (as proxied by latitude) has no direct effect on income, once institutions are controlled for. However, the 2SLS estimation strategy employed by these authors does not take account of the bi-modal distribution of country-level income per capita, as displayed in Figure 4.1. As Conway and Deb (2005, p.291) point out, given that “a multimodal distribution is the ‘textbook’ representation of a finite mixture distribution”, patterns such as the one displayed in Figure 4.1 “present compelling evidence that the standard method is misspecifying the model and that a finite mixture is more appropriate”. I therefore repeat the analysis using a finite mixture model. The results are reported in Table 4.4, where I also present results from AJR’s original 2SLS approach for comparison.

The table shows the sharp contrast in results based on the two methodologies. Column 1 presents the results from AJR’s 2SLS regression, which shows that in the second stage, which includes the instrumented institutions variable, latitude has no direct effect on income. However, in columns 2 and 3, I demonstrate, using the FMM methodology, that the effect of institutions on income is only significant in the rich country component, while latitude is a significant determinant of income for poor countries. In columns 4, 5 and 6 I repeat the analysis, using bootstrap methods to calculate standard errors. Again I find that the institutions variable is significant only for the rich country component. Latitude is no longer significant in either component when using the bootstrap method to calculate standard errors.

In the FMM regressions, component 1 represents just 8% of the sample of

64 countries. When we inspect the posterior probability of belonging to component 1 (τ_1), we find that the six countries identified with this component are: Ethiopia ($\tau_1=100\%$), Pakistan ($\tau_1=92\%$), Bangladesh ($\tau_1=90\%$), Tanzania ($\tau_1=75\%$), Sierra Leone ($\tau_1=69\%$) and Niger ($\tau_1=52\%$). In other words, component 1 represents relatively poor countries in the sample, with four of the six being sub-Saharan African countries, while the other two are South Asian countries. Again, these results indicate that the institutions variable is not a significant predictor of income for relatively poor countries, especially those in sub-Saharan Africa.

4.4 Monte Carlo simulations

In this section I use Monte Carlo simulations to examine directly the influence on estimation results of a finite mixture distribution.⁵ I generate artificial income data, based on the estimated parameters from the finite mixture model regression reported in Table 4.4 (columns 2 and 3). In other words I assume that the estimated parameters from the FMM regression are the ‘true’ population parameters. I then estimate income regressions by OLS for a range of assumptions about the underlying distribution from which the data were generated. I contrast estimation results for the baseline case where the data are generated from a single regime versus cases that involve a mixed distribution.

This estimation procedure mimics the standard 2SLS approach in AJR, given that I use the predicted institutions variable both in generating the artificial income data and in estimating the income equation. This approach allows me to abstract from the issue of instrument quality. By using the predicted institutions variable, I am able to focus on the effects of the mixed distribution for the idealised scenario where the institutions variable is exogenous (or an ideal instrument exists).

The Monte Carlo simulations are carried out as follows: First, I take the

⁵The procedures I follow in generating the Monte Carlo simulations are based on Conway & Deb (2005).

results of the FMM regression in Table 4.4 (columns 2 and 3) and use these as my chosen ‘true’ parameter values in generating the artificial income data. I also choose values for π_1 , the probability of a country being in regime 1 (the poor regime), starting with the baseline case of $\pi_1 = 1$ (the non-mixture case).

I then take the actual latitude data and the predicted values of the institutions variable and randomly assign each observation to one of the two regimes (according to the chosen probability π_1). Using these data for the explanatory variables, the artificial income data are then generated for each observation, based on the chosen parameters for each regime, plus a normally distributed random error term (ϵ_j) with the finite mixture estimated variance (σ_j^2). The artificial income data are then used to estimate a regression of income on institutions and latitude using OLS. This estimation procedure assumes that all observations come from the same distribution. However, this is only ‘true’ for my generated data for the baseline case of $\pi_1 = 1$.

This process of generating artificial income data and using these to estimate coefficients on latitude and institutions is repeated 2000 times, in order to generate a large sample of results. I report the 5th, 50th and 95th percentile values from my sample of OLS results, for the estimated latitude coefficient. I also report the proportion of times (out of my sample of 2000 replications) that the estimates lead the hypothesis of no effect of latitude on income (i.e. the latitude coefficient is 0) to be rejected at the 10 and 5% levels of significance (power of the test). This shows how likely one is to find a statistically significant effect of latitude on income.

The entire Monte Carlo procedure, as described above, is repeated for a range of values of π_1 (the mixture ratio) in order to investigate the effects on the estimation results of moving from a non-mixture case ($\pi_1 = 1$) to a mixed distribution. In the initial Monte Carlo runs, I set the ‘true’ parameter values on latitude and institutions to reflect a situation where latitude is only a significant predictor of income in the poor regime, while institutions are only significant in the rich regime (as indicated by the FMM results reported in Table 4.4). I also report results where it is assumed that institutions is a significant explanatory variable within both regimes.

The results of the Monte Carlo simulations are reported in Table 4.5. Not surprisingly, for the case with all observations assigned to the poor regime (rows 1 and 5), the coefficient on latitude is estimated very precisely, and the null of a coefficient on latitude equal to zero is rejected 100% of the time.⁶ However, as I increase the proportion of countries randomly assigned to the rich regime, the estimates of the coefficient on latitude become less precise and the test begins to lose power. In the first set of simulations (rows 1-4), where it is assumed that institutions are only significant in the rich regime, this process is relatively gradual. However, by the time we have assigned just 15% of observations to the poor regime, we see some negative values for the coefficient on latitude and the null hypothesis is rejected just one in five times at the 10% level of significance.⁷

In the second set of simulations (rows 5-8), where it is assumed that the institutions variable is a significant predictor of income within both regimes, this loss of precision and power occurs much more rapidly. Even with 85% of countries still assigned to the poor regime, we start to observe negative estimates of the coefficient on latitude, while the null is rejected less than half of the time, even at the 10% significance level.

These simulation results show how the standard 2SLS estimation approach, as used by AJR, could make latitude appear unimportant, even when the true relationship between income and latitude is large and significant, at least for relatively poor countries. In other words, ignoring the bi-modality of world income could be obscuring the true effects of geography (as proxied by latitude) in the standard approach adopted in these well known and widely cited studies.

⁶The power of the test in this case also reflects, in part, the relatively low estimated variance in the poor regime (σ_1^2) from the FMM regression. This makes sense given that countries in the poor regime are in a poverty trap and therefore their incomes vary relatively little.

⁷The results of the FMM regression using AJR's data, reported above, show a relatively small proportion of their sample classified as poor (in this case, just 8% of countries). However, in previous studies that demonstrate the bi-modality of global income, as cited above, a much larger proportion of countries - often around 85% - tend to be classified as poor. This is also the pattern observed in Figure 4.1, which shows a majority of countries clustered around the lower mode of the income distribution. I therefore experiment with a wide range of values for π_1 .

4.5 Conclusions

The results presented here cast doubt on the strength (and certainty) of the conclusions in AJR and Acemoglu (2008) in relation to the relative merits of institutions and geography as the *fundamental* sources of comparative economic development. The AJR results appear to be sensitive to the countries included in the estimation sample, while it may be that a small number of influential observations are primarily responsible for the observed chain of causation from settler mortality to institutional quality to income.

A related finding from my analysis is that institutions do not appear to explain the variation in income across relatively poor countries (i.e. the poor regime in the FMM regressions), or for the African sub-sample of countries. The FMM results also suggest that latitude may exert a significant influence on income within the poor country regime, although this finding is not robust, as demonstrated by the bootstrapped FMM results. It may be that there are simply too few observations in the poor country regime. Then again, the same argument could be applied to the lack of robustness in relation to the findings for the institutions variable. We use Monte Carlo simulations to confirm that ignoring the bi-modality of global income could cause geography to appear unimportant.

Sample size is clearly an issue here. The base sample in the AJR paper only contains 64 observations (countries). Although over a hundred country observations are included in the AJR data, the sample is restricted due to incomplete data for certain variables, particularly the institutions variable and its instrument (settler mortality). One way forward for the analysis of questions relating to the fundamental sources of comparative development may be to use sub-national data in order to increase sample size. In physics, it has been noted that “observations of ever smaller physical effects have been forcing ever greater changes in our world view”, in part thanks to “ever more powerful telescopes and measuring instruments” (Deutsch, 1997, p.56-7). Nordhaus (2006) makes the point that moving from country level data, which generally provide about 100 observations, to the G-Econ (sub-national) dataset, which covers over 25,000 grid cells, “is analogous to pictures from the Hubble telescope, which provide clear and crisp answers to many previously difficult and fuzzily answered questions” (p.3510). The urgency

of the debate over appropriate policies in response to the threat of climate change has also placed a greater emphasis on the ability to combine high resolution climate data with economic data. Incidentally, the results presented in this chapter also correspond to Nordhaus's (2006) finding that geography is an important source of income differences for tropical Africa, relative to high-income regions.

The Monte Carlo simulation results show how the standard 2SLS estimation approach, as used by AJR, could make latitude appear unimportant, even when the true relationship between income and latitude is large and significant, at least for relatively poor countries. In other words, ignoring the bi-modality of world income could be obscuring the true effects of geography (as proxied by latitude) in the standard approach adopted in these well known and widely cited studies. In the next chapter, I propose an alternative geography variable - environmental volatility - which is more likely to have a causal relationship with income, and test directly its effect on income across rich and poor regimes, using the finite mixture model approach.

Table 4.1: OLS vs IV Regressions of log GDP per capita, splitting the sample by median income

	OLS	2SLS	2SLS 'rich' only	2SLS 'poor' only	2SLS 'rich' only bootstrap s.e.	2SLS 'poor' only bootstrap s.e.
	(1)	(2)	(3)	(4)	(5)	(6)
Avg. protection against exprop. risk 1985-1995	0.47*** (0.06)	1.00*** (0.22)	0.62*** (0.13)	-5.42 (46.36)	0.62* (0.34)	-5.42 (173.87)
Latitude	1.58** (0.71)	-0.65 (1.34)	-0.05 (0.64)	1.30 (17.00)	-0.05 (0.84)	1.30 (1229.61)
Obs.	64	64	32	32	32	32

Note: The dependent variable in each case is log GDP per capita in 1995.
All data are from AJR.
Standard errors in parenthesis. Columns 5 and 6 report bootstrapped standard errors.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4.2: Bootstrapped 2SLS - excluding specific influential observations

	2SLS full sample	2SLS excl. SGP & GMB	2SLS excl. SGP, GMB, MLI & AUS
	(1)	(2)	(3)
Avg. protection against exprop. risk 1985-1995	1.00 (3.50)	0.88** (0.28)	1.03 (12.88)
Latitude	-0.65 (4.83)	-0.29 (1.35)	-0.92 (53.40)
Obs.	64	62	60

Note: The dependent variable in each case is log GDP per capita in 1995. All data are from SGP is Singapore, GMB is Gambia, MLI is Mali, and AUS is Australia. Bootstrapped standard errors in parenthesis. $*p < 0.10$, $**p < 0.05$, $***p < 0.01$.

Figure 4.1: Kernel density plot of country-level income per capita, 1995 PPP

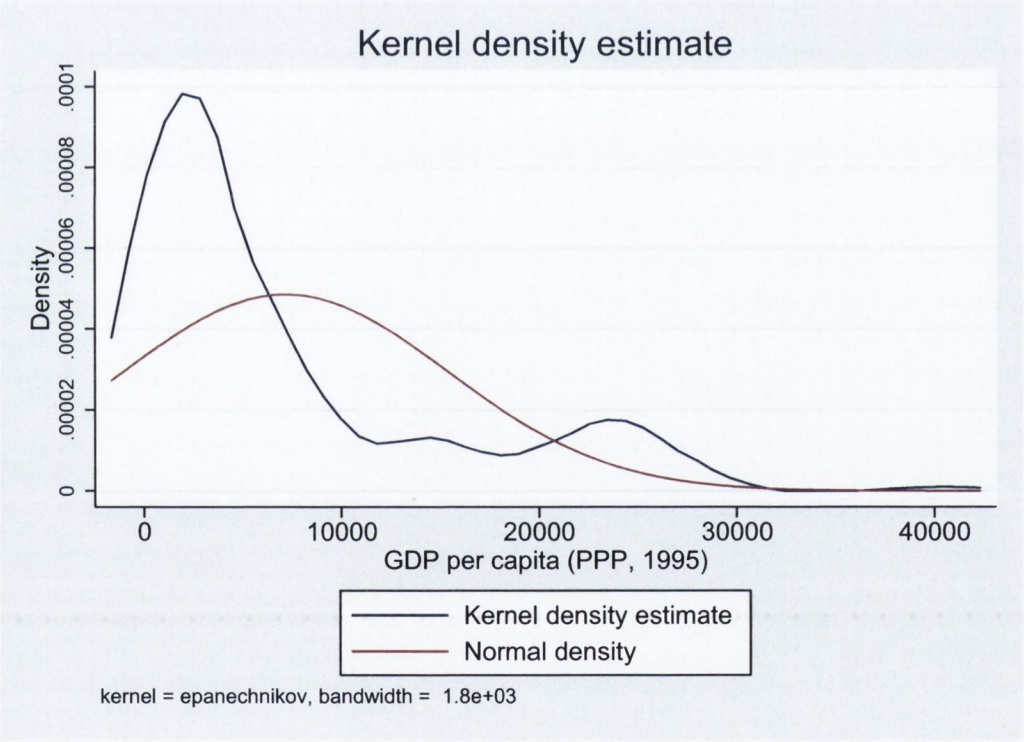


Table 4.3: IV Regressions of log GDP per capita - replication of AJR's Table 4

	Base sample		Base sample without Neo-Europes		Base sample without Africa		Base sample with continent dummies		Base sample Africa only	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
<u>Two-Stage Least Squares</u>										
Average protection against expropriation risk 1985-1995	1.00*** (0.22)	1.00 (3.50)	1.21*** (0.35)	1.21 (6.58)	0.58*** (0.12)	0.58*** (0.13)	1.11** (0.46)	1.10 (12.27)	6.09 (45.53)	6.09 (14.18)
Latitude	-0.65 (1.34)	-0.65 (4.83)	0.94 (1.46)	0.94 (7.39)	0.04 (0.84)	0.04 (0.68)	-1.18 (1.76)	-1.18 (38.24)	-10.99 (106.98)	-10.99 (25.59)
Asia dummy							-1.05* (0.53)	-1.05 (7.04)		
Africa dummy							-0.44 (0.42)	-0.44 (3.46)		
“Other” continent dummy							-0.99 1.00	-0.99 26.51		
<u>First-stage for Average protection against expropriation risk 1985-1995:</u>										
Log European settler mortality	-0.51*** (0.14)		-0.39*** (0.14)		-1.14*** (0.25)		-0.34* (0.18)		-0.03 (0.22)	
Latitude	2.00 (1.34)		-0.11 (1.49)		0.99 (1.43)		2.01 (1.39)		2.21 (2.43)	
R^2	0.30		0.13		0.47		0.33		0.05	
Number of observations	64	64	60	60	37	37	64	64	27	27

Note: Odd columns replicate results in Table 4 of AJR. Even columns are same with bootstrapped standard errors. Standard errors in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4.4: 2SLS vs FMM

	2SLS	FMM		2SLS	FMM	
		Comp. 1 'poor'	Comp. 2 'rich'		Comp. 1 'poor'	Comp. 2 'rich'
	(1)	(2)	(3)	(4)	(5)	(6)
					Bootstrapped s.e.	
Avg. protection against exprop. risk 1985-1995	1.00*** (0.22)	-0.10 (0.07)	1.08*** (0.14)	1.00 (3.50)	-0.10 (0.67)	1.08*** (0.29)
Latitude	-0.65 (1.34)	4.73*** (0.45)	-1.07 (0.83)	-0.65 (4.83)	4.73 (3.19)	-1.07 (2.10)
Prob. of comp.1 (π_1)		0.08 (0.04)			0.08 (0.04)	
Obs.	64			64		

Note: The dependent variable in each case is log GDP per capita in 1995.

All data are from AJR.

Models 1, 2 and 3 are standard 2SLS and FMM regressions.

Standard errors in models 4, 5 and 6 are bootstrapped with 1,000 replications.

FMM bootstrapped standard errors based on 927 replications.

(The model did not converge in 73 out of 1,000 attempted replications).

Standard errors in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4.5: Monte Carlo simulations

β_{11}	β_{12}	β_{21}	β_{22}	π_1	Percentiles of estimated coefficient			Power of test	
					5th	50th	95th	10%	5%
0.00	1.08	4.73	0.00	1.00	4.56	4.73	4.91	1.00	1.00
0.00	1.08	4.73	0.00	0.85	2.62	4.05	5.17	0.99	0.99
0.00	1.08	4.73	0.00	0.50	0.47	2.39	4.19	0.73	0.63
0.00	1.08	4.73	0.00	0.15	-0.99	0.75	2.44	0.22	0.13
1.08	1.08	4.73	0.00	1.00	4.56	4.73	4.91	1.00	1.00
1.08	1.08	4.73	0.00	0.85	-0.94	4.11	8.74	0.41	0.29
1.08	1.08	4.73	0.00	0.50	-4.27	2.35	9.10	0.17	0.09
1.08	1.08	4.73	0.00	0.15	-4.16	0.49	5.98	0.12	0.06

Note: β_{11} and β_{12} are the parameters on the institutions variable for regimes 1 and 2. β_{21} and β_{22} are the parameters on latitude for each regime. π_1 is the probability of a country being assigned to regime 1 (the poor regime).

Chapter 5

Environmental volatility and the takeoff to modern economic growth

5.1 Introduction

The dreadful unpredictability of the rain has its effect, too, in keeping men poor. Even in the fat years a farmer has to bear the lean years in mind. He will rarely grow cotton or groundnuts to earn extra cash, with which he could buy better tools or fertilizer. Instead, he will sow more grain and store it in his granary, as insurance.

Inside the third world - Paul Harrison

Once again, in 2012, a prolonged period of drought in the Sahel region of West

Africa is giving rise to fears of an impending humanitarian catastrophe. The depressingly familiar narrative was played out just last year (2011) in the eastern Horn of Africa. While socio-economic factors determine whether environmental shocks such as drought become full-blown humanitarian disasters (Sen, 1983), the trigger remains environmental. East African ‘feast and famine’ culture may be linked to ‘see-saw’ rainfall anomaly patterns (as described in e.g. Janowiak, 1988; Nicholson, 2000).¹ However, the links between environmental volatility and economic prosperity have rarely been tested in the literature.

It has been recognized that poor countries suffer greater environmental volatility and are more vulnerable to such volatility than their higher income counterparts. According to the Stern report (Stern, 2007) developing countries are on average warmer, and suffer from higher variability in rainfall than higher income countries. Poor country vulnerability to environmental shocks stems from a combination of structural and institutional factors. In general, poorer countries tend to be heavily dependent on agricultural output - a sector which is clearly weather-dependent. Poorer economies are also less resilient to shocks of various kinds due to relatively weak financial sector and institutional development.² Dependence on agriculture was the status of all economies at one point in their development. It may be, therefore, that environmental factors were important determinants of which countries or regions developed first and which were left behind.

Geography clearly plays a significant role in the evolution of socio-economic development. One only has to look at maps of the world showing concentrations of population to appreciate that people - and their economic activities - tend to cluster in specific geographic locations. In particular, the highest densities of both population and economic activity are to be found near coasts or along ocean-navigable rivers (Gallup *et al.*, 1999). Numerous authors have also noted

¹Verschuren *et al.* (2000) link long-term (inter-decadal) rainfall patterns with periods of prosperity in Africa. On a shorter time-horizon, Jury (2002) uses summer rainfall patterns in South Africa to predict economic output in the following year.

²In Chapter 2, I demonstrated the importance of financial sector development - and access to credit in particular - in coping with the economic effects of natural disasters. More generally, the influence of financial sector development on growth, poverty and inequality is discussed in Levine *et al.* (2000) and also in Demirguc-Kunt & Levine (2009). Loayza *et al.* (2007) cite financial sector development as one of their economic ‘shock absorbers’. The role of institutional factors in coping with environmental shocks is discussed in Kahn (2005) and also in Noy (2009).

the relationship between latitude and income - from classical economists such as Montesquieu and Adam Smith, to more recent contributions such as Parker (2000).³

While standard neo-classical models of economic growth have been agnostic about the role of geography, geographic-based explanations of economic development have enjoyed something of a renaissance in recent years. These geography-based theories of economic development propose a number of mechanisms through which geographic factors influence economic outcomes. As noted by Adam Smith, coastal access matters for trade (see Sachs *et al.*, 2001). It has also been suggested that differences in continental orientation may have been an important factor in determining why trade - and the consequent spread of technology - expanded more rapidly in some regions than in others (Diamond, 1997).⁴

Another strand of this literature focusses on the effects of geography and environment on the disease profiles of different regions. For example, Sachs & Malaney (2002b) detail the developmental impacts of malaria, the prevalence of which is highly climate-dependent.⁵ Strulik (2008) argues for an indirect channel

³It should be noted that some early contributions on the link between geography and economic development tended, to a greater or lesser extent, to rely on apparently racist explanations of the observed correlation. For example, Montesquieu in his *Spirit of the Laws* famously characterized people living in the tropics as slovenly. This interpretation has since proven to be unfounded. One particularly revealing study by Clark (1987) shows that migrant workers from less productive economies, when moving to more productive economies, achieve levels of productivity at least comparable to native workers. Whatever makes tropical regions less productive in economic terms is clearly to do with the prevailing local conditions - whether environmental or other - and not a result of the nature or characteristics of the people living in those regions.

⁴Diamond (1997) argues that an East-West continental axis - such as the Eurasian continent - facilitated easier movement of people and therefore ideas, due to the relative uniformity of climatic conditions across the continent - compared with the diversity of climatic conditions to be found in a North-South oriented continent such as Africa, which acted as barriers to the movement of people and therefore to the establishment of trade routes. Diamond also suggests that the availability of domesticable crops and animals in certain regions - Eurasia in particular - allowed those regions to develop agriculture first. The advent of agriculture enabled higher population densities, giving these regions a decisive head-start in the development of the technologies - Diamond's titular *Guns, Germs and Steel* - that would later be used to dominate other regions both politically and economically.

⁵Hales *et al.* (2003) detail the effects of extreme weather events (droughts, floods etc.) on the disease profile of affected regions. Similarly, Pascual *et al.* (2008) argue that rainfall variability plays a "complementary and interacting" role with the inherent disease dynamics of malaria. Tang *et al.* (2009) present evidence of the effects of climate on health (and the interaction with

of causation from geography to economic performance, via child mortality, fertility and child expenditure.⁶ A related mechanism is discussed and tested in Masters & McMillan (2001), where the authors argue that winter frost has a significant impact on economic development by killing off pests and pathogens that reduce human and agricultural productivity.

These geographic explanations of comparative economic development have not been without controversy. A number of authors have argued that, while geographic or environmental factors may have some indirect historical link with economic development through their influence on the formation of institutions, the direct correlation between geography and income per capita disappears once institutions are properly controlled for (e.g. Rodrik, 1999; Acemoglu *et al.*, 2001, 2003; Easterly & Levine, 2003). However, the evidence presented by these authors is far from conclusive. For a start, most of these studies have tended to use latitude as their measure of geography, which is at best a proxy for other factors (such as climate). Furthermore, even once institutions have been properly controlled for, the link between geographic or environmental factors and levels of income per capita persists. For example, Parker (2000) and more recently Nordhaus (2006) have shown that links between geography and income persist even within countries, while of course most economically-relevant institutions are constant within a given country. Similarly, Sachs (2003) shows that malaria transmission continues to have a direct effect on income, even when controlling for institutions. Finally, geography (and climate in particular) has been shown to affect institutional formation in ways that are likely to be of contemporary relevance for studies of comparative economic development, and not merely as an historical curiosity (as seems to have been argued by the institutionalists).⁷

income), finding particularly strong impacts in African countries. Tol *et al.* (2007) discuss a similar type of interaction between climate, health and development, while The Lancet has characterized climate change as “the biggest global health threat of the 21st century” (Lancet, 2009).

⁶The model in Strulik (2008) draws on the quality-quantity (Becker *et al.*, 1990) and demographic transition (Galor & Weil, 2000; Bloom *et al.*, 2001) concepts.

⁷For example, the social psychologist Evert Van de Vliert has a whole series of recent papers on the effects of climate on socio-cultural institutional formation (e.g. Van de Vliert, 2007). A pre-cursor to this work can be found in Wittfogel’s *Oriental Despotism* (Wittfogel, 1957). Climatic factors have also been linked with various forms of social or political unrest and conflict.

A further criticism of the above literature (including contributions from both the geography and institutions advocates) is that it has tended to treat global income as a single distribution, whereas a number of authors (e.g. Quah, 1996, 1997; Bloom *et al.*, 2003) have demonstrated that the global distribution of country-level GDP per capita is bi-modal. Failing to take account of such bi-modality in the underlying distribution of the dependent variable can skew regression results and obscure the true effect of the explanatory variables (as demonstrated by Conway & Deb, 2005). Figure 5.1 presents a kernel density plot of country level income per capita in our sample, clearly displaying a strong bi-modal distribution.⁸ In Chapter 4, I demonstrated that ignoring the bi-modality of global income could lead the ‘institutionalist’ authors mistakenly to dismiss the role of geography in economic development.

In Section 5.3 below I present a model, based on Acemoglu & Zilibotti (1997), which demonstrates that the process of economic development is vulnerable in its early stages to shocks and setbacks - or in other words bad luck - which affect not only income levels for those countries in the low-income equilibrium (or trap) but also the probability of transitioning out of this equilibrium, i.e. of achieving takeoff. I reinterpret this unspecified risk as weather risk and posit that the key mechanism separating the lucky from the rest in the development draw, is the volatility of the natural environment.

As far as I am aware, this is the first time that the implications of Acemoglu and Zilibotti’s model have been tested empirically. The theoretical framework, as well as providing the justification for the emphasis on a bi-modal income distribution, also accounts for a number of empirical consistencies in the growth data. As a result, we are able to re-conceptualize the notion of the takeoff to modern

A recent paper by Bruckner & Ciccone (2011) uses rainfall variations as predictors of democratic change in African countries, with rainfall data used as an instrument for changes in income. Rainfall variability has often been used as a proxy for income shocks in the micro-development literature - see for example, Jacoby & Skoufias (1997). Similarly, a number of recent papers have linked environmental or climatic variability with the onset of civil conflicts. Paul Collier argues in *The Bottom Billion* that “setbacks to growth caused by rainfall shocks make civil war much more likely” (Collier, 2007, p.20). Hsiang *et al.* (2011) test the effect of climate on conflict directly, finding that El Nino events are strongly correlated with the onset of civil conflicts.

⁸Similarly, Figure 5.2 shows the distribution of country level income per square km. Again the pattern presented is clearly not a uni-modal normal distribution.

economic growth.

In the analysis that follows, I use a flexible estimation strategy, that allows for differential effects of the explanatory variables across two income groups.⁹ I show that even when controlling for institutions, geography continues to have a significant influence on income, once we allow for a bi-modal income distribution. Bloom *et al.* (2003) use a similar estimation strategy to test geographic determinism against a poverty trap (multiple-equilibria) model. They find empirical evidence in support of a poverty trap model, with geographic factors having a significant influence on income in the low-income equilibrium and also on the probability of being in the high-income equilibrium.¹⁰

First, as a further motivation to the empirical analysis which follows, I discuss the concept of economic takeoff. Based on the characterization of takeoff from the theoretical model presented in Section 5.3, and the empirical evidence on growth discussed below, I develop a new conceptualization of the takeoff process, which has long been a key (if controversial) element in the analysis of economic development.

5.2 Defining the takeoff to modern economic growth

One of the challenges of this paper is in defining the takeoff to modern economic growth. Easterly (2006) argues that takeoffs, in the classical sense of an abrupt transition from low or stagnant growth to sustained positive growth, are relatively rare in the data. However, this is not the kind of takeoff that fits with the theoretical framework we are using. In our framework (based on Acemoglu & Zilibotti, 1997), undiversified economies grow slowly. They gradually diversify leading to endogenous productivity growth. If undisturbed, growth rates in these economies will accelerate, at least for a time, as they diversify activities. However,

⁹I use the finite mixture model (FMM) programme in Stata, as developed by Partha Deb (see Deb & Trivedi, 1997; Conway & Deb, 2005).

¹⁰Tol (2011) employs a similar empirical strategy to test the demo-economic model of Strulik (2008). Tol also finds evidence of a bi-modal income distribution, with hotter countries being poorer, with higher mortality and higher fertility.

in the early stages of development, with low levels of diversification, economies are vulnerable to chance events. Thus our framework allows for both the gradual acceleration of growth and for false starts or periodic growth collapses.

This characterization of the takeoff fits well with evidence presented in Easterly (2006). Hausmann *et al.* (2005) show that most growth accelerations are not sustained. These authors also show that such episodes (accelerations followed by rapid reversals) are more likely in poorer countries. A number of authors discuss the apparent instability of growth over time (e.g. Easterly *et al.*, 1993). Similarly, Rodrik (1999) discusses the prevalence in the data of growth collapses. Evidence discussed in that paper (and based on Collins *et al.*, 1996), suggests that the Asian Tiger growth miracles appear miraculous only as a result of growth collapses in the Middle East and Latin America after 1973 (productivity growth in particular). This evidence fits well with the idea that growth will continue along the lines determined by neo-classical forces, unless interrupted by negative shocks.¹¹

Rodrik (1999) points to instances of social conflict as potential explanations of the frequency of growth collapses. As mentioned earlier, a number of recent studies have linked social conflict with climatic variability - thus reinforcing the emphasis here on the link between geographic or environmental factors and the takeoff. Easterly (2006) refers to the spatial concentration of takeoff episodes (under his definition). Again this points to some role for geography in determining the timing of the takeoff.

The theoretical model presented here, in line with empirical evidence, characterizes takeoff as a slow and uncertain process, as opposed to the classical, rather deterministic view of takeoff as a once-off leap from stagnation to a path of rapid and smooth convergence to the frontier economies. In reality, the path to prosperity appears to be particularly perilous in its early stages. This reconceptualization of economic takeoff could have profound implications for development policy.

The traditional view of takeoff as a discrete jump from a poverty trap to a

¹¹The analysis contained in Young (1995) also makes the rapid growth of the Asian Tigers look less miraculous and more a simple product of factor accumulation.

steady growth path towards prosperity suggested a big push policy of once-off investment or aid programmes. Acknowledging that the process of development is a slow and perilous one - vulnerable to shocks and setbacks of various kinds - will require a re-orientation of development policy, something which we return to in the conclusions. In the following sections, we test the idea that the apparent randomness of growth, especially notable in relatively poor countries, may be explained by the predominance in certain regions of a capricious natural environment.

5.3 Modelling the takeoff

Classical theories of economic growth (Solow, 1956; Rostow, 1959) emphasise capital accumulation as the mechanism for economic growth and development. Capital scarcity tends to be problematic in developing countries, where a lack of domestic resources combined with capital market imperfections retards the provision of the (physical, educational and health) infrastructure necessary to enable economic development. This paper models the takeoff to modern economic growth as being dependent on sufficient capital accumulation, which itself depends on the stochastic process of natural environmental volatility.

The aim of the model presented here (based on Acemoglu & Zilibotti, 1997) is essentially to model the transition, or takeoff, from stagnant subsistence-based agriculture to modern economic growth. The model will show that the timing of the takeoff to a modern growth regime is dependent on luck. I posit the natural environment as the source of this luck (both good and bad). The model assumes incomplete financial markets in the sense that agents cannot borrow to fund investment or fully insure themselves against failure of their enterprises. Diversification (into non-agricultural activities) reduces aggregate risks, thus stimulating further entrepreneurship and growth. However, indivisibilities in diversification activities (i.e. those other than subsistence-based agriculture) mean that agents must accumulate a minimum threshold of assets before they can avail of diversification opportunities.

Capital scarcity in the early stages of development means that only a limited number of projects can get underway, due to indivisibilities in the form of minimum size requirements and start-up costs. This lack of diversification limits the degree of risk sharing - creating vulnerability to random shocks - thus introducing a large amount of uncertainty in the growth process. This greater level of vulnerability also causes agents to “seek insurance by investing in safe but less productive assets. As a result, poor countries will endogenously have lower productivity” (Acemoglu & Zilibotti, 1997, p.710).

The poverty-trap mechanism in the model is therefore a combination of a capital scarcity story (in part resulting from capital market imperfections which prevent agents from simply borrowing the required level of capital to overcome the diversification threshold), with an element of non-convexity, in the sense that investing in the risky activity has positive externalities from society’s point of view - by reducing aggregate risk and making it more attractive to invest in riskier, but more productive, enterprises.

The theoretical model (based on Acemoglu & Zilibotti, 1997), may be formalized as follows: Agents choose the level of savings, s_t , and investment in the safe asset, ϕ_t , and risky asset, F_t^j , to maximize (discounted) lifetime consumption across all (equally likely) states of nature, j ,

$$\max_{\{s_t, \phi_t, F_t^j\}} \ln(c_t) + \beta \int_0^1 \ln(c_{t+1}^j) dj \quad (5.1)$$

where the discount rate is represented by β .

Maximization is subject to the following conditions, including a standard budget constraint, which constrains the sum of first period consumption, c_t , and savings not to exceed first period wages, w_t ,

$$c_t + s_t \leq w_t \quad (5.2)$$

the division of savings between the safe and risky assets,

$$s_t = \phi_t + \int_0^1 F_t^j dj \quad (5.3)$$

and a second period budget constraint, equating second period consumption, c_{t+1}^j , in state of nature j , with second period income from investments, which depends on the price of capital, ρ_{t+1}^j , and the returns to the safe and risky assets in that state of nature.

$$c_{t+1}^j = \rho_{t+1}^j (r\phi_t + RF_t^j) \quad (5.4)$$

Acemoglu & Zilibotti (1997) show that, in equilibrium, savings represent a constant fraction of first period wages

$$s_t^* \equiv s^*(w_t) = \frac{\beta}{1+\beta} w_t \quad (5.5)$$

This level of savings is then divided, in equilibrium, between investment in the safe and risky assets, as follows:

$$\phi_t^* = \frac{(1-n_t)R}{R-rn_t} s_t^* \quad (5.6)$$

$$F_t^{j,*} = \begin{cases} F_t^* \equiv \frac{R-r}{R-rn_t} s_t^* & \forall j \leq n_t \\ 0 & \forall j > n_t \end{cases} \quad (5.7)$$

where $n_t \in [0, 1]$ measures the fraction of ‘open’ sectors.

Risky investments, F^j , in sector j , pay RF^j if state j occurs and nothing otherwise. The returns to the risky investment are assumed to exceed those of the safe asset (i.e. $R > r$). However, there is also a minimum size requirement for investing in the risky asset, which is increasing in j . In other words, smaller sectors are ‘opened’ first. The demand for risky assets (5.7) is increasing in n_t , i.e. in the degree of diversification (or the fraction of open sectors).

Production in the model is assumed to follow a standard Cobb-Douglas production function

$$Y_t = AK_t^\alpha L_t^{1-\alpha} \quad (5.8)$$

Then, assuming a fixed labour supply and normalizing the labour supply to 1 (i.e. $L_t = 1$), wages and the price of capital are determined as follows:

$$W_{t+1}^j = (1 - \alpha)A(K_{t+1}^j)^\alpha \quad (5.9)$$

$$\rho_{t+1}^j = \alpha A(K_{t+1}^j)^{\alpha-1} \quad (5.10)$$

The dynamics of the capital stock follow a Markov process. The following expression describes the equilibrium law of motion of K :

$$K_{t+1} = \begin{cases} \frac{r(1-n_t^*)}{R-rn_t^*} RA(1-\alpha)[\beta/(1+\beta)] K_t^\alpha & \text{prob.}(1-n_t^*) \\ RA(1-\alpha)[\beta/(1+\beta)] K_t^\alpha & \text{prob. } n_t^* \end{cases} \quad (5.11)$$

With a greater proportion of sectors open (i.e. for higher n_t) risk-sharing is

enhanced, thus increasing the probability of carrying a ‘large’ capital stock over to the next period. Ultimately for an economy experiencing good draws - i.e. consistently carrying over a large capital stock to the next period - the following threshold will be reached:

$$\text{for } K_t > \left(\frac{D}{A(1 - \alpha)[\beta/(1 + \beta)]} \right)^{1/\alpha}, n_t^* = 1 \quad (5.12)$$

i.e. full diversification. This economy has ‘taken off’ to the extent that it has achieved full diversification and subsequently grows, consistently (i.e. without reversals or growth collapses), at a rate proportional to that of the frontier economies.

This model of economic development relies on some form of luck to distinguish rich from poor. An obvious question then is what is the mechanism by which countries are divided into those experiencing good draws that go on to achieve full diversification and a modern economic growth regime, and those that experience bad draws and become stuck in a low-equilibrium poverty trap? Accumulating the level of assets necessary to enable diversification depends on the stochastic process of returns to agricultural activities and the ability to consistently earn above subsistence income from farming. Returns to agriculture are obviously weather-dependent. A less favorable environment will constrain the ability to earn above-subsistence income from agricultural activities. Environmental volatility may also lead to the destruction of accumulated assets and/or the run-down of savings. I thus hypothesize that the degree of environmental volatility is the crucial mechanism that distinguishes the lucky from the rest in the development draw. This hypothesis is tested explicitly in the next section.

5.4 Empirical analysis

In this section I present my empirical analysis, which is comprised of several distinct elements. First, to further motivate the regression analysis, I attempt to

define by hand the poverty line (i.e. the line that divides our sample of countries into rich and poor - the income threshold for economic takeoff) which best fits the income data. This involves finding the income threshold for splitting the sample in two, which minimizes the sum of deviations from group means (in income per capita). Having defined the best-fit poverty line in this way, I then test for statistically significant differences in group means for a range of variables of relevance to the study. Secondly, I motivate the focus in the regression analysis on rainfall volatility by examining in detail its relationship with income per capita, for our sample of 135 countries.

I test directly the hypothesis that environmental volatility is the mechanism that distinguishes the lucky from the rest, using a finite mixture model (FMM) regression approach (see Deb & Trivedi, 1997; McLachlan & Peel, 2000). The FMM approach explicitly accounts for the bi-modality of the global income distribution. This approach allows me to specify the number of regimes or components - in this case two, i.e. rich and poor. Each regime is a linear model of the dependent variable (income) in its explanatory variables. We are thus able to identify separately the marginal effects of a given explanatory variable in each regime. The two regimes are linked by a logit model. Regime-sorting in the model is endogenous, enabling us to specify the variables that we expect to influence the division of the sample into regimes or components and to estimate the magnitude of the effect of each variable.

I first confirm the finding of Bloom *et al.* (2003) that global income is indeed better represented by a two-regime model rather than a single regime (i.e. that the global distribution of income per capita is indeed bi-modal). This finding confirms the appropriateness of a finite mixture model approach to the regression analysis. Failing to take account of the bi-modality of global income could obscure the true relationship between the explanatory variables and income per capita, even where all relevant factors have been controlled for (Conway & Deb, 2005).

Next, I develop the regression analysis to test the effects of the explanatory variables on income per capita across each regime (i.e. separately for 'rich' and 'poor' countries) and also on the probability of being included in a given regime (i.e. of being classified 'rich' or 'poor' by the model). As mentioned, my focus is

on environmental volatility (in the form of rainfall variability). However, I also include a range of geography and climate variables, which are selected on the basis of their expected causal relationship with income, as well as a number of the most commonly used cultural or institutional variables from the existing literature on comparative economic development. Finally, I check the consistency of my results using income per square kilometer as an alternative dependent variable.

5.4.1 Data

My sample consists of 135 countries, having excluded very small states (those with populations of less than 500,000 people) and those that are heavily dependent on oil production (countries for which oil production in 2010 represented over 30% of GDP).¹²

The economic data that I use come from standard sources. For income per capita I use data on income per capita at purchasing power parity (at current prices), taken from the Penn World Tables and averaged over the period 1980-2008. As an alternative dependent variable, I also use income per unit area (i.e. total GDP divided by the surface area of each country, giving income per kilometer squared).

The climatic data come from the Climate Research Unit (CRU) at the University of East Anglia. The data used are for the period 1961-1990. My preferred measure of environmental volatility is the within-year variability of rainfall, which I measure using the coefficient of variation (*CoV*) of monthly rainfall (where rainfall observations for each month are averaged over the 30-year period 1961-1990). Inter-annual rainfall variability appears to be less informative.¹³ First, this mea-

¹²Eleven countries were excluded on the basis of being highly dependent on oil - Angola, Azerbaijan, Congo (Rep.), Equatorial Guinea, Iraq, Kuwait, Libya, Oman, Saudi Arabia, Timor-Leste, United Arab Emirates. Three further countries, Djibouti, Qatar and Bahrain, were identified as outliers - based on their income-climate relationship - and omitted on this basis. Qatar and Bahrain are small countries in the Middle East, and are both also heavily reliant on oil and associated revenues. Djibouti, another relatively small country, while not an oil producer, also has an atypical economy that is largely based on services related to its strategic location as a transit hub.

¹³Inter-annual rainfall variability is the standard deviation of total annual rainfall in a given country for the period 1901-2000, divided by the mean total annual rainfall over the same

sure has less variation across countries than the intra-annual measure. It is also likely to have reduced explanatory power as a result of spatial and within-year aggregation.¹⁴ I also include the average maximum temperature, over the sample period.

The variable *landcoastal* was used by John Luke Gallup and his co-authors in a number of papers on geography and income (e.g. Gallup *et al.* , 1999) and represents the % of a country's land within 100km of a coast or (ocean-navigable) river.¹⁵ I also include a measure of socio-cultural homogeneity; specifically, a measure based on the percentage of a country's population in the largest single group that shares the same ethnic, linguistic and religious characteristics (labelled *homogeneity* in regressions). Finally, I also take a measure of institutional quality from the literature on comparative economic development; specifically I use "average protection against expropriation risk" from Acemoglu *et al.* (2001), based on data from Political Risk Services (see William D. Coplin & Sealy, 1991).¹⁶

5.4.2 The best-fit poverty line

Taking income per capita in levels, the threshold poverty line that minimizes the sum of squared deviations from group means is at \$22,300 with 145 out of a sample of 190 countries classified as 'poor' according to this threshold.¹⁷ This clearly appears too high an income level to represent a realistic poverty line and is most likely being driven by a number of outliers in the sample - small countries with extremely high levels of income per capita. I therefore take logs of income per capita and recalculate the best-fit poverty line. In this case the threshold occurs at \$5,315 with 76 countries defined as 'poor'. This represents a more

period. The longer period is used in an attempt to capture a greater range of year-to-year volatility.

¹⁴Of course, the intra-annual rainfall variability measure that I use is also spatially aggregated within each country.

¹⁵The original data are available from Gallup's website at <http://pdx.edu/econ/john-luke-gallup>.

¹⁶This variable is only available for 99 out of the 135 countries in my sample.

¹⁷The best-fit poverty line was calculated for the full sample of 190 countries for which income data were available.

intuitive level for our best-fit poverty line and also compares reasonably well with the World Bank country classification system, which lists 86 countries in the combined ‘low income’ and ‘lower-middle income’ categories.

Taking this threshold as distinguishing rich from poor countries, I test for differences in average characteristics between the two groups across a range of variables of relevance to my study.¹⁸ I find that poor countries on average; are located in lower latitudes ($n=135$, $t=6.96$, $p\text{-value } 0.0000$); are hotter ($n=134$, $t= -6.90$, $p\text{-value } 0.0000$); drier ($n=134$, $t=1.58$, $p\text{-value } 0.0585$, one-sided); and more likely to be landlocked ($n=135$, $t= -3.55$, $p\text{-value } 0.0005$). In line with the predictions of the Acemoglu and Zilibotti theoretical model and existing empirical evidence on the instability of growth rates (as discussed in Section 5.2), I also find that poor countries are more dependent on agricultural output ($n=128$, $t= -13.74$, $p\text{-value } 0.0000$) and have higher variability of growth rates ($n=104$, $t= -3.76$, $p\text{-value } 0.0003$).¹⁹

In line with the theory and evidence presented in Masters & McMillan (2001), I find that poor countries have less seasonal temperature variation ($n=133$, $t= 4.57$, $p\text{-value } 0.0000$), and are less exposed to frost ($n=135$, $t= 5.02$, $p\text{-value } 0.0000$). Unsurprisingly, poor countries are also more likely to be involved in violent conflict ($n=135$, $t= -4.25$, $p\text{-value } 0.0000$). Turning to the question of environmental volatility, I find that poor countries have higher within-year (intra-annual) rainfall variability ($n=134$, $t= -7.59$, $p\text{-value } 0.0000$), and higher year-to-year (inter-annual) rainfall variability ($n=134$, $t= -1.73$, $p\text{-value } 0.0860$). I also find that poor countries have higher exposure to drought risk ($n=135$, $t= -2.51$, $p\text{-value } 0.0133$).²⁰

These group characteristics fit well with the characterization of poor countries

¹⁸This analysis was carried out on the reduced sample of 135 countries, of which 61 were classified as ‘poor’ according to the best-fit poverty line, as calculated above.

¹⁹Agricultural dependence is based on the share of agriculture in total output in 2005 (figures from the World Bank). Variability of growth rates based on the standard deviation of the annual percentage change in per capita GDP (1979-2007), taken from the Penn World Tables (v 6.3).

²⁰Data on exposure to frost and drought risk are from Munich Re’s NATHAN Country Natural Hazard Overview dataset and were obtained directly from Munich Re. The conflict variable is a dummy variable equal to one if the country in question has been a primary party in conflict during the period 1980-2009, according to data from The Centre for the Study of Civil War (CSCW) at the Peace Research Institute Oslo (PRIO).

in the theoretical framework presented above. However, such group differences do not necessarily represent a causal relationship. In the sections that follow I present regression analyses aimed at teasing out the possible relationship between environmental volatility and income. First, I take a closer look at that relationship, using a graphical analysis.

5.4.3 Income and environmental volatility

Figure 5.3 shows the relationship between income per capita and environmental volatility (as represented by rainfall variability) for my sample of 135 countries. There appears to be a strong negative correlation between income and the variability of rainfall. A single regression line fitted for the full sample has a slope of -2.45 ($n=134$, $t=-9.80$, $p\text{-value } 0.000$) and explains 42% of the variation in income per capita across our sample. Israel and Zimbabwe, with similar levels of rainfall variability but radically different levels of wealth, would appear to be outliers in this relationship. Interestingly, as we might expect, all of the western European countries and their offshoots (highlighted in green) are tightly clustered in the top left of the graph.²¹ In contrast, sub-Saharan African countries (highlighted in red) are generally clustered towards the bottom right of the graph.

From a simple visual inspection of the scatter plot, it looks as though the relationship between income and environmental volatility is relatively flat for high levels of income (e.g. above a log income per capita value of around 9.5). The relatively tight clustering of the richer countries in the top left corner of the graph may also be indicative of a two-regime system, as would be implied by the bi-modality of global income and also predicted by the theoretical framework. Separate regression lines fitted for the two groups of countries either side of this (arbitrary) threshold are shown in Figure 5.3.²² As we would expect, the relationship between income and environmental volatility for the rich group of countries is relatively weaker; the regression line has a slope of -0.53 ($n=27$, $t=-3.34$, p -

²¹The ‘offshoots’ are the four rich post-colonial countries; USA, Canada, New Zealand and Australia.

²²I take a threshold of a log income per capita value of 9.48, to ensure that all of the western European countries are included in the high income group.

value 0.003) and explains 28% of the variation in income across this group. For the poorer group of countries, there is a stronger relationship; the regression line fitted for this group has a slope of -1.82 ($n=107$, $t= -7.91$, $p\text{-value } 0.000$), and explains 37% of the variation in income across this group.

It is notable that each of these separate regression lines represents a somewhat weaker relationship between income and environmental volatility than for the entire sample of countries combined. However, this may still represent a better description of the data, if indeed income is bi-modally distributed. Indeed the observed weaker relationship between income and environmental volatility for the rich group of countries fits with the theoretical framework, which predicts that countries are vulnerable to shocks only up to a certain threshold, beyond which they have diversified sufficiently to no longer experience growth setbacks as a result of bad luck. This also makes sense intuitively - relatively rich countries do not tend to suffer major growth setbacks as a result of environmental shocks.

In any case, this type of highly partial analysis is only useful as a guideline for further investigation. The evidence presented in Figure 5.3 suggests a *prima facie* case for a relationship between income and environmental volatility, but one which becomes weaker (or perhaps even disappears) for relatively high income levels. A further question which arises is what separates the rich from the rest? It may be that environmental volatility has no effect on income beyond some rich-country income threshold. However, this does not mean that environmental volatility was not a factor in determining which countries have joined this rich group. Indeed, the relatively strong relationship between income and environmental volatility for the full sample of countries (combining rich and poor groups) is suggestive of just this sort of relationship.

5.5 Regression results

In this section I present the results of regression analysis, based on a series of finite mixture model regressions, as discussed above. I focus on three geography variables that are likely to be causally related to income - *maxtemp*, *landcoastal*

and the measure of rainfall volatility (*CoV*). I also include a measure of institutional quality (*Avepr*) and socio-cultural homogeneity, in the regressions. The finite mixture model procedure has difficulty converging to maximum likelihood as more explanatory variables are added to the model, particularly given the relatively small samples we are using. For this reason, I restrict the analysis to the relatively parsimonious model specifications presented in this section.

5.5.1 Confirming the bi-modality of world income

In Table 5.6.1 I present a simple test of a two-regime model versus a single regime, essentially replicating Bloom *et al.* (2003)'s Table 3 on my data. The first column of Table 5.6.1 reports the results of a simple OLS regression of log GDP per capita (averaged over 1980-2009) on a constant, while columns 2 and 3 report the results of a similar two-regime FMM regression. The results presented here, based on the sample of 135 countries, are quite similar to those reported by Bloom *et al.* (2003). In the single regime, average log GDP is 8.15 with a standard deviation of 1.3. In the two-regime model, the probability of being in the lower-income regime (Regime I) is 0.84, with an average log GDP for this group of 7.80 and a standard deviation of 1.10. The richer group has an average log GDP of 10.00, with countries in this group much more tightly clustered around the same income level - the standard deviation for this group is just 0.17. These group characteristics fit well with the graphical evidence presented in Figures 5.1 and 5.3, which show most low- to middle-income countries fairly widely distributed around a lower level of income, with a smaller proportion of the sample tightly clustered around relatively high income levels. This description of the data also fits closely with the predictions of the theoretical framework outlined in Section 5.3.

The second last row of the table reports the log likelihood values for the two models, indicating an improvement in model fit as we move from a single regime to the two regime model. To test if this difference is statistically significant, I run a likelihood ratio test. The test statistic resulting from comparing the single regime with the two regime model is reported in the last row of Table 5.6.1.

However, as discussed in detail in Bloom *et al.* (2003), with mixture models the regularity conditions for the likelihood ratio test statistic to have its usual asymptotic chi-squared distribution do not hold (see also Chapter 6 of McLachlan & Peel, 2000). We therefore do not have a standard critical value to compare with our test statistic result. Bloom *et al.* (2003) use Monte Carlo studies to estimate critical values for the likelihood ratio test statistic in the mixture model context. They find a 5 percent critical value for the model with no explanatory variables of 11.66 (compared with what they term the ‘conservative’ approach of Dickens & Lang (1985) which would result in a 5 percent critical value of 7.81). The 1 percent critical value that they estimate for this model is 15.13. Based on these critical values, the observed test statistic of 28.66 would seem to indicate a highly significant improvement in model fit for the two-regime model versus a single regime, thus confirming the bi-modality of the global income distribution and the appropriateness of applying a finite mixture model with two regimes to my analysis.²³

5.5.2 What divides the rich from the rest - comparing single variable explanations

Having established the superior fit of the two-regime model to my data, I attempt in this section to identify the factors that separate the rich from the rest. I run five separate FMM regressions with income per capita as the dependent variable. Each time, I include a single explanatory variable in the logit model that determines

²³I also fitted a finite mixture model with three components, which resulted in a low income regime with roughly 76% of countries and an average log GDP per capita of 7.68, a high income regime with 17% of countries and average log GDP per capita of 9.99 and a middle income regime with 7% of countries and average log GDP per capita of 8.76. The log likelihood for the three regime model improved to -208.65. However, the likelihood ratio test statistic for comparing this to the two regime model was 5.97. Thus, based on the critical values calculated by Bloom *et al.* (2003), the three component model appears to offer little improvement over the two-regime model. As McLachlan & Peel (2000, p.176) argue, it is “sensible in practice to approach the question of the number of components in a mixture model in terms of an assessment of the smallest number of components in the mixture compatible with the data.” In the remainder of the analysis, I therefore concentrate on two-regime models.

regime sorting. Each regime is restricted to be a simple linear regression on a constant (as in the previous section). This setup is intended to facilitate a direct comparison of the geography and institutional variables as determinants of a country being classified as ‘rich’ or ‘poor’ in the model.²⁴

The results of these regressions are reported in Table 5.6.1. As is clear from the table, the three geography variables are each highly significant predictors of whether a given country is classified as rich or poor by the mixture model. As we would expect, and in line with existing geography-based theories of development, countries with higher maximum temperatures are more likely to be classified as poor by the model, while those with a greater proportion of their land area on or near the coast (or ocean navigable rivers) are less likely to be classified as poor. Interestingly, the rainfall volatility variable (*CoV*) is also a highly significant predictor of country classification. In line with the theoretical framework, countries with higher rainfall volatility are more likely to be classified as poor by the model.

Both the institutions variable (*Avepr*) and the socio-cultural homogeneity variable have the expected signs, indicating that countries with higher scores on these indices are less likely to be classified as poor. However, neither of these variables are statistically significant predictors of country classification. While institutions and cultural factors are clearly important factors in economic development, they do not appear to be as good as geographic factors at explaining the observed division between rich and poor (countries) in the global income distribution.

5.5.3 Multiple variable regressions

Tables 5.6.1, 5.6.1, 5.6.1 and 5.6.1 present the results of a series of FMM regressions aimed at identifying the effects of our geography and socio-cultural or institutional variables on income for each of the two regimes we have identified. In Tables 5.6.1 and 5.6.1 the dependent variable in each of the six regressions

²⁴Note that for the regressions presented in Table 5.6.1 I restrict the sample in each case to only those observations for which I have data on each of the five variables, in order to ensure comparability of the results.

is income per capita (averaged over the period 1980-2009) in logs. In each of the first three models, rainfall volatility has a significant negative effect on income in both regimes. The other geography variables, *maxtemp* and *landcoastal* (entered separately in models 2 and 3) only appear to have a significant effect on income within the poor regime. In contrast to some of the existing literature on the fundamental sources of economic development, models 4, 5 and 6 demonstrate that the geography variables remain significant, at least within the poor regime, even when controlling for institutions or socio-cultural homogeneity. These results indicate that geography variables are better at explaining income for relatively poor countries, while the institutions and socio-cultural variables appear to be better predictors of income within the rich regime.²⁵ Again, the results fit very well with the characterisation of economic development presented in the theoretical section. In particular, the finding that geography variables - and rainfall volatility in particular - are significant predictors of income for relatively poor countries, but no longer exert a significant effect on income within the rich regime (once institutions and culture are controlled for) corresponds to the theoretical prediction that relatively poor countries are vulnerable to shocks and chance events, but that this vulnerability is reduced as development leads to greater diversification of economic activity.

Tables 5.6.1 and 5.6.1 include results from essentially the same 6 model specifications. However, the dependent variable in each regression this time is GDP per square km. Assuming some degree of human mobility throughout the course of history, income per unit area may be a more meaningful outcome variable than income per capita for investigations of the causes of long term economic develop-

²⁵The institutions variable in particular is likely to be endogenous with respect to long-term economic development. In this sense, it is a less meaningful explanatory variable for long-term economic development. However, we wanted to include a measure of institutions in order to show that our results remain robust even when controlling for institutions. Of course, the potential endogeneity of institutions means that simply including a measure of institutional quality in our regressions may not be sufficient to properly control for their influence on development. We therefore repeated models 4 and 6 using an instrumented version of the institutions variable. The instrument used was the *settlermortality* variable introduced by Acemoglu *et al.* (2001). The results for model 4 were very similar to those presented in Table 5.6.1. However, model 6 converged to the “dummy variable” solution (discussed in Bloom *et al.*, 2003) when we included the instrumented version of *Aveexpr*. In other words the model did not identify two distinct regimes in this case.

ment, given that income per unit area takes account not just of the concentration of wealth per person in a given area (country), but also of the concentration of people in that area.

The results presented in Tables 5.6.1 and 5.6.1 show a very similar pattern to those presented in Tables 5.6.1 and 5.6.1. The geography variables exert a significant influence on income per square km, particularly within the poor regime, while the institutions variable has a more significant effect within the rich regime. Interestingly, cultural homogeneity does not appear to significantly affect income per square km for either the rich or poor regimes.

5.6 Conclusions

We can identify two regimes in the data - i.e. rich and poor. My results suggest that hot, landlocked countries with unpredictable (i.e. volatile) rainfall are more likely to be stuck in the poor regime, and furthermore, that these poor countries are vulnerable to environmental volatility, which appears to delay their takeoff. Institutions and socio-cultural factors also matter for economic development, but their effect appears to operate predominantly on income within the rich regime. In contrast to some of the existing literature on comparative economic development (which does not take account of the bi-modality of global income), I find that the geography variables included in the regressions - and rainfall volatility in particular - remain significant, even when controlling for institutions and culture. These results may have important implications for development policy, for studies of the expected costs of future climate change and also for the academic literature on comparative economic development.

I demonstrate the importance of taking account of the bi-modality of global income. I focus on geographic variables that are likely to be causally related to income - rather than using a causally meaningless proxy such as latitude. In particular, the rainfall volatility variable represents both a novel empirical contribution and also a theoretically motivated choice as a fundamental source of economic development. As far as I am aware, this chapter represents the first

attempt to test empirically the predictions of Acemoglu and Zilibotti's model of economic development.

5.6.1 Future research directions

The analysis presented in this chapter represents a first step in a research agenda that takes explicit account of the evolving vulnerability of economies to environmental factors, in particular rainfall volatility. The discussion and theoretical section presented a clear link between rainfall volatility - as a potential source of 'bad luck' - and economic takeoff. Vulnerability to rainfall shocks was shown to depend on both structural and institutional factors. As economies grow, diversifying their activities (to become less reliant on agricultural or primary sector output), and developing better risk-coping mechanisms, this vulnerability is reduced. Future empirical work could attempt to model more explicitly this dynamic interaction between economic structure and vulnerability to shocks during the development process. In particular, it would be useful to try to understand whether a structural shift in the economy represents the outcome of a sustained takeoff in economic growth, or a pre-requisite for such episodes to occur.

A related issue is the development of formal risk coping mechanisms - i.e. financial market development - and the provision of credit and insurance services that can be used to ameliorate the longer-term impacts of temporary disruptions to income. In Chapters 2 and 3, I emphasised the role of credit markets in facilitating recovery from natural disasters. A worthwhile extension of this research might be to combine the insights from my analysis of natural disasters with the longer-term modelling framework in this chapter in order to examine the dynamic interaction of economic structure and financial market development, and their co-evolution with economic development. The analysis of these inter-relationships will not be straightforward, given the difficulty of establishing the direction of causality (e.g. does a structural shift precede the development of financial markets, or does financial market development enable the shift away from primary production?). However, such difficult questions represent important and interesting challenges for further research in this area.

In order to test empirically these sorts of dynamic interactions, it may be necessary to move away from the static, cross-sectional type of analysis used in this chapter. An alternative modelling approach would be to use regime-shift models to identify structural breaks in historical growth data, representing episodes of economic takeoff, and to examine the factors associated with the timing of such episodes.

The analysis presented here uses a measure of institutional quality that is standard in the literature on comparative development. However, in future work, it would be interesting to attempt to understand what elements of institutional quality - a term that covers a broad range of factors of relevance to economic development - are important for reducing vulnerability. For example, it has been shown in the micro literature that land tenure rights are an important factor in determining risk-coping behaviour in an agricultural setting. Might differences in this particular form of institutional structure explain cross-country variation in vulnerability to weather shocks?

The theoretical framework presented in this chapter emphasises the role of risk mitigation (through diversification of activities) as a means of stimulating investment in higher productivity activities. This creates a virtuous cycle of growth and diversification leading to endogenously higher rates of investment and higher returns. The constraint on the setting in motion of such a virtuous cycle - in the context of an undiversified economy, with weak formal risk-sharing mechanisms - is the risk of an external shock that wipes out investment. This logic could also apply to other forms of risk that constrain high productivity investment, for example the threat of conflict or corruption leading to the expropriation of assets. The relationship between these other sources of risk, environmental risk and the takeoff to modern economic growth could represent an interesting nexus for further research. As an example of the interaction of these distinct forms of risk, Miguel *et al.* (2004) have demonstrated a link between climate and conflict, potentially illustrating an additional channel of effect from environmental factors to economic development.

As mentioned in Section 5.2, Easterly (2006) has pointed out the spatial concentration of takeoff episodes. Such patterns could also indicate the importance of

geographic factors in determining the timing of the takeoff. Another worthwhile extension to this research would be to examine directly the diffusion of modern economic growth across regions, and its possible relation to environmental factors such as periods of relatively benign climatic conditions (see for example Verschuren *et al.* , 2000).

Table 5.1: Testing a single regime vs ‘twin peaks’			
Dependent variable: Log GDP per capita (1980-2009 average)			
	Single Regime	Two Regimes	
		Regime I	Regime II
	(1)	(2)	(3)
Constant	8.15 (0.11)	7.80 (0.12)	10.00 (0.05)
SD of regime disturbance	1.295	1.10	0.17
Prob. regime I			0.84 (0.038)
Log likelihood	-225.97		-211.64
Likelihood ratio test of two regimes vs. one regime			28.66
Obs.	135		
Note: Standard errors in parenthesis.			

Table 5.2: Single variable logit regressions

Effect on probability of being 'poor'	
Rainfall CoV	10.20*** (2.83)
Maxtemp	0.20*** (0.05)
Landcoastal	-2.23*** (0.81)
Avexpr	-4.14 (2.58)
Homogeneity	-2.16 (1.42)

Note: Standard errors in parenthesis.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5.3: Rainfall volatility and income per capita

	Dependent variable: Income per capita (1980-2009 average, in logs)					
	(1)		(2)		(3)	
	('rich')	('poor')	('rich')	('poor')	('rich')	('poor')
Rainfall CoV	-2.40*** (0.28)	-2.29*** (0.28)	-0.38** (0.17)	-1.71*** (0.26)	-2.57*** (0.38)	-2.05*** (0.30)
Maxtemp (log)			-0.01 (0.12)	-0.92*** (0.20)		
Landcoastal					0.21 (0.28)	0.85*** (0.28)
Prob 'poor'	0.89 (0.05)		0.91 (0.04)		0.86 (0.06)	
Observations	134		132		132	
Log likelihood	-184.07		-166.33		-177.03	

Note: standard errors in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5.4: Rainfall volatility and income per capita (*continued*)

	Dependent variable: Income per capita (1980-2009 average, in logs)					
	(4)		(5)		(6)	
	('rich')	('poor')	('rich')	('poor')	('rich')	('poor')
Rainfall CoV	0.23 (0.16)	-1.47*** (0.27)	-1.31*** (0.42)	-2.53*** (0.36)	-0.16 (0.22)	-1.41*** (0.37)
Maxtemp (log)					0.07 (0.14)	-0.92** (0.36)
Landcoastal					0.30* (0.17)	1.10*** (0.37)
Avexpr	0.41*** (0.03)	0.44*** (0.06)			0.57*** (0.04)	0.19 (0.12)
Homogeneity			3.91*** (0.64)	-0.29 (0.66)	0.77*** (0.27)	-0.25 (0.43)
Prob 'poor'		0.86 (0.07)		0.62 (0.13)		0.63 (0.10)
Observations	99		125		87	
Log likelihood	-99.94		-162.46		-78.87	

Note: standard errors in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5.5: Rainfall volatility and income per square km

	Dependent variable: GDP (1980-2009 average) per square km, in logs					
	(1)		(2)		(3)	
	('rich')	('poor')	('rich')	('poor')	('rich')	('poor')
Rainfall CoV	-0.89*	-0.19***	-0.93**	-0.08***	-0.95**	-0.15***
	(0.52)	(0.03)	(0.46)	(0.03)	(0.44)	(0.03)
Maxtemp (log)			0.04	-0.15***		
			(0.30)	(0.02)		
Landcoastal					1.13***	0.14***
					(0.34)	(0.04)
Prob 'poor'	0.73		0.63		0.71	
	(0.05)		(0.05)		(0.05)	
Observations	132		130		130	
Log likelihood	-20.02		-14.66		-10.82	

Note: standard errors in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5.6: Rainfall volatility and income per square km (*continued*)

	Dependent variable: GDP (1980-2009 average) per square km, in logs					
	(4)		(5)		(6)	
	('rich')	('poor')	('rich')	('poor')	('rich')	('poor')
Rainfall CoV	-0.01 (0.50)	-0.07*** (0.02)	-0.90 (0.58)	-0.19*** (0.03)	-0.33 (0.66)	-0.07* (0.04)
Maxtemp (log)					0.53 (0.63)	-0.04 (0.04)
Landcoastal					1.04** (0.41)	0.20*** (0.04)
Avexpr	0.25*** (0.08)	0.01* (0.01)			0.41*** (0.13)	0.02 (0.01)
Homogeneity			0.36 (1.27)	0.07 (0.04)	-0.55 (1.02)	-0.02 (0.04)
Prob 'poor'		0.52 (0.07)		0.25 (0.05)		0.68 (0.06)
Observations	98		125		86	
Log likelihood	-26.28		-10.41		-5.04	

Note: standard errors in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Figure 5.1: Kernel density plot of country-level income per capita, averaged over 1980-2009

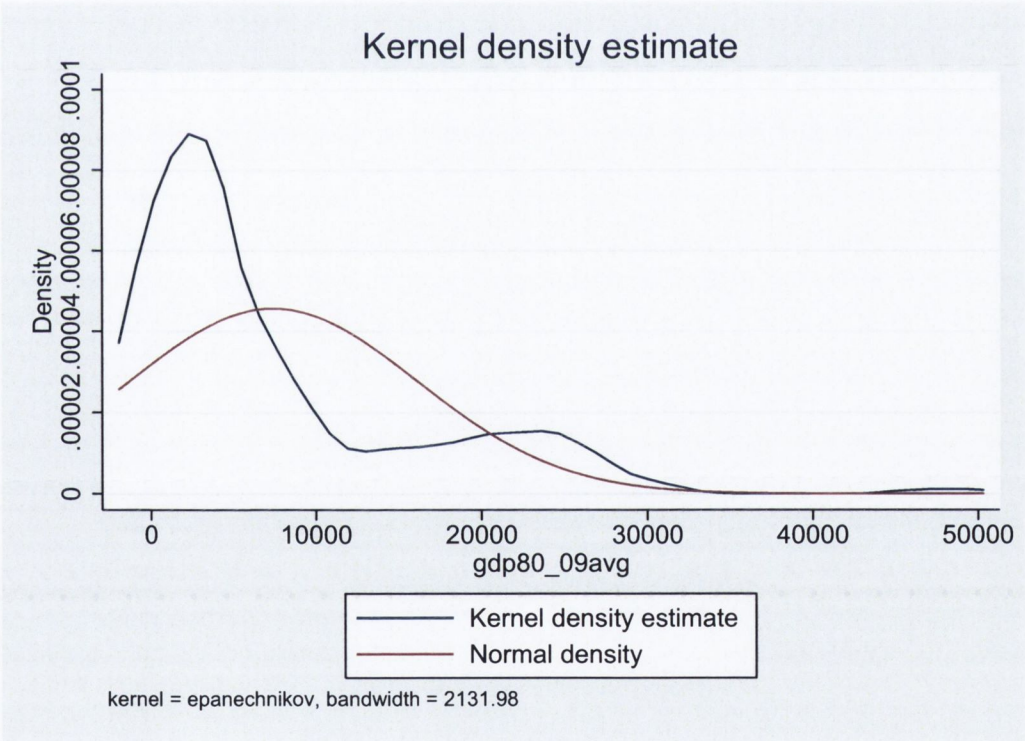
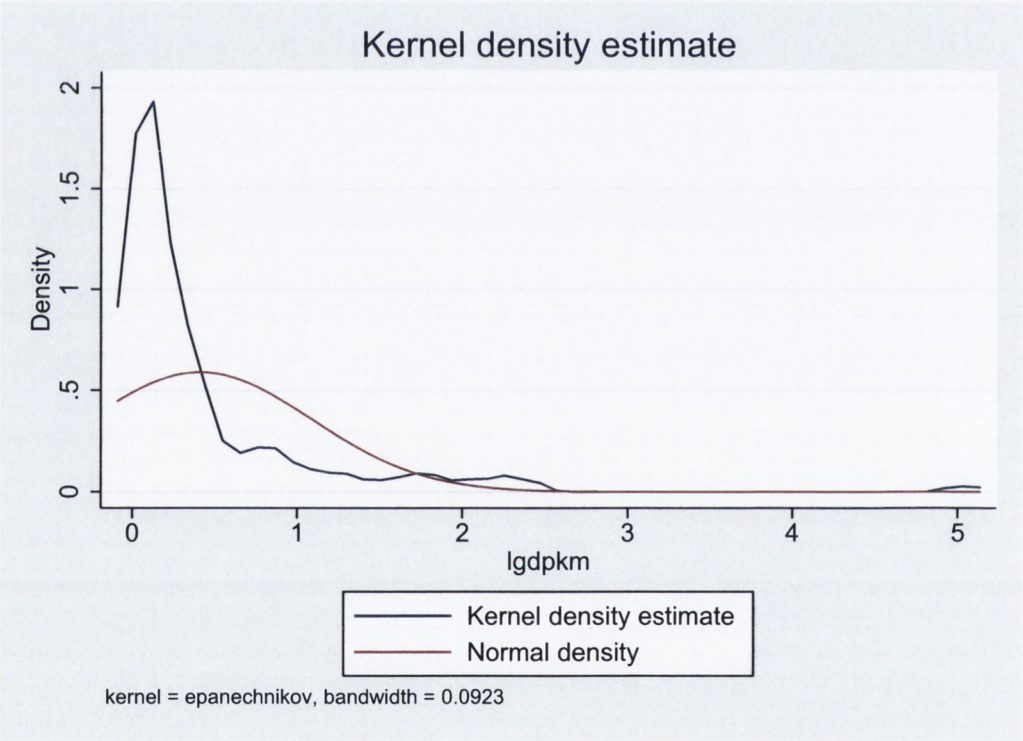


Figure 5.2: Kernel density plot of country-level income per square km, averaged over 1980-2009



Log GDP per capita (1980-2009 average)

CoV_Intra_Annual

Reg. line (lgdp>9.48)

Reg. line (lgdp<9.48)

SSA

W.Europe & Offshoots

Chapter 6

Conclusions

This thesis examines the effects of environmental shocks on economic development. I distinguish between two types of environmental shocks; extreme (large-scale, but rare) shocks resulting from natural disasters; and chronic exposure to (smaller-scale) shocks resulting from unpredictable or volatile rainfall. The analytical approach to these two types of environmental shocks is quite distinct. In the case of natural disasters, my focus is on the medium-term economic dynamics in response to the shock, while in relation to rainfall volatility I analyse its long-term relationship with comparative (i.e. cross-country) levels of economic development.

The findings in Chapters 2 and 3 are important, firstly, because they demonstrate that disasters are not merely transient blips along the path to economic prosperity. While in the past, disasters have received relatively little attention from the mainstream academic literature, the results presented in this thesis show that disasters represent a meaningful threat to the development prospects of poorer countries. As the World Bank has recently pointed out, natural disaster risks require explicit consideration in macroeconomic planning or policy scenarios (Thomas, 2011).

My findings also have implications for the policy response to disasters. While

there is little that can be done to prevent the occurrence of a purely natural event or phenomenon, this thesis has argued and demonstrated that the impacts of disasters are dependent on human (in)action. Clearly, the direct impacts of disasters - the amount of damage caused, people affected or killed - is dependent on the *ex-ante* vulnerability of the affected region and its population. However, I have also shown that the longer-term effects for the economy, as well as for health and education outcomes, are dependent on economic as much as physical infrastructure. In particular, credit availability appears to play a significant role in mitigating the medium to long-term impacts of disasters.

A disaster, by its very definition, represents a negative wealth (or welfare) shock. To prevent that negative shock from having longer term economic and social impacts, the affected communities require access to the appropriate 'shock absorbers'. A farmer whose crops or livestock are destroyed by a natural disaster, requires access to finance to prevent that transient loss of income, or destruction of assets, from turning into a permanent reduction in productivity as a result of reduced investment in education and productive capital. Interestingly, my results suggest that access to credit is crucial for investment in education following disasters, but that income (including aid flows) matters more for the longer-term health impacts of disasters. My results also highlight a gender dimension to the health and education impacts of natural disasters. The unequal impacts of disasters across genders has been noted previously. However, my findings show that this inequality persists beyond the short-term, direct effects of disasters.

My research on natural disasters and economic development presented here, might also be extended in several important directions. Chapters 2 and 3 demonstrated the importance of economic - and financial - conditions in determining the economic impacts of disasters, with a specific focus on the interaction between disaster events and financial sector development. However, it may also be interesting to examine the effects of *ex-post* financial responses to disasters. In particular, aid and other financial flows into a country in response to disaster events may have the effect of mitigating the medium to longer-term impacts for economic development. Then again, this may not be the case if aid flows are (understandably) concentrated on emergency assistance and rescue efforts rather

than reconstruction and long-term economic recovery. This distinction between emergency aid - with its necessarily short-term focus - and the more long-term oriented forms of development aid, may represent a worthwhile area for further research. In particular, it may be possible to test empirically the relative contributions of each type of aid for disaster recovery over the medium to long-term. Future research might also examine the potential for innovative forms of disaster assistance - various types of credit schemes for example, or weather-indexed insurance - in helping to mitigate the lasting economic impacts of disasters identified in this thesis.

In Chapters 4 and 5, I analyse the role of geography - environmental volatility in particular - in the 'origins' of comparative economic development. The results presented indicate that some of the existing literature in this area has been premature in dismissing the role of geography in explaining comparative economic development. In general, my results show that geography variables are better at explaining income for relatively poor countries, while institutions and socio-cultural variables appear to be better predictors of income for rich countries.

The contrast between the results presented here and the findings in much of the existing literature in this area, can be explained by two major insights that motivated my analysis. The first relates to the evolving nature of economic vulnerability. Put simply, not all countries are equal. In fact, it has been demonstrated - and confirmed here - that the global distribution of income can be characterized as bi-modal, indicating the presence of two distinct equilibria or growth regimes across rich and poor countries. Such a pattern is consistent with various modern theories of economic growth that include poverty traps or non-convexities. It is likely, therefore, that the relationship between income and any putative explanatory variable will be non-uniform across rich and poor countries. In my analysis, I account for such non-uniformity, by employing a sophisticated finite mixture model approach to the empirical analysis in Chapters 4 and 5.

Secondly, in Chapter 5, I focus my analysis on a geography variable - rainfall volatility - that is both theoretically motivated and that, unlike some of the proxies for geography used in previous studies (e.g. latitude), has a plausible causal relationship with economic development. As discussed in Chapter 1, uncertainty

- or the volatility of income - can be a key motivating factor in the accumulation of precautionary savings. Although aggregate (macro) volatility - which cannot be diversified nationally - is generally viewed as the main driver of precautionary savings at the macro level, for developing countries with undiversified economies, or low levels of financial market development, idiosyncratic risks are also problematic to insure. The theoretical model discussed in Chapter 5 demonstrates that, for countries facing regular setbacks - possibly as a result of a capricious natural environment - the requirement to accumulate precautionary reserves as a form of insurance will lead to endogenously lower levels of productivity. The relationship between natural disaster risk - or environmental volatility more generally - and the allocation of resources between safe but unproductive assets versus higher risk investments, represents another potentially fruitful area for future research.

The combined findings from Chapters 4 and 5 represent a significant contribution to the literature on comparative economic development. Development is a complex, dynamic and evolving process. Single-factor explanations of comparative levels of economic development are therefore necessarily inadequate. My findings show that it is premature to discount the role of geography. I show that both geography and institutional variables exert significant influence on development, but possibly at different stages of the development process. The findings presented in this thesis will also be of relevance for assessments of climate change risk. The link between climate change and extreme weather events remains controversial. However, most climate models predict an increase in the intensity and variability of rainfall. A better understanding of how such climate patterns affect economic development is therefore crucial to facilitating more accurate estimation of the expected costs of a given future climate scenario.

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Appendix A

Mathematical appendix

The basic model

Agents maximize utility

$$U = \ln(C_1) + B\ln(C_2) \tag{A.1}$$

subject to

$$C_1 + RC_2 = F(K_1, L_1) - I_1 + RF(K_2, L_2) \tag{A.2}$$

Lagrangian

$$L = \ln(C_1) + B\ln(C_2) - \lambda[C_1 + RC_2 - F(K_1, L_1) + I_1 - RF(K_1 + I_1, L_2)] \tag{A.3}$$

$$dL/dC_1 = 1/C_1 - \lambda = 0 \quad (\text{A.4})$$

$$dL/dC_2 = B/C_2 - \lambda R = 0 \quad (\text{A.5})$$

$$dL/dI_1 = -\lambda + \lambda RF_{K2} = 0 \quad (\text{A.6})$$

Giving the first-order conditions

$$C_2 = C_1 \left(\frac{B}{R} \right) \quad (\text{A.7})$$

$$RF_{K2} = 1 \quad (\text{A.8})$$

Investment effects in a credit-constrained economy

Assuming a Cobb-Douglas production function, (A.8) can be rewritten as follows

$$R = \frac{1}{\alpha(K_1 + I_1)^{(\alpha-1)} L_2^{(1-\alpha)}} \quad (\text{A.9})$$

By applying the quotient rule (given that R is expressed here as a fraction) we have

$$\frac{dR}{dK_1} = \frac{-\alpha(\alpha-1)(K_1 + I_1)^{\alpha-2} L_2^{(1-\alpha)}}{(\alpha[K_1 + I_1]^{\alpha-1} L_2^{(1-\alpha)})^2} \quad (\text{A.10})$$

which yields, after some simplification

$$\frac{dR}{dK_1} = \frac{-(\alpha-1)(K_1 + I_1)^{\alpha-2}}{\alpha L_2^{(1-\alpha)} (K_1 + I_1)^{2\alpha-2}} > 0 \quad (\text{A.11})$$

given that we assumed $0 < \alpha < 1$ and therefore $(\alpha-1) < 0$.

We can use this value of dR/dK_1 to solve for dI_1/dK_1 as follows. From (A.8) and using the Cobb-Douglas production function, we have

$$I_1 = \left(\frac{1}{\alpha L_2^{(1-\alpha)} R} \right)^{1/(\alpha-1)} - K_1 \quad (\text{A.12})$$

then

$$\frac{dI_1}{dK_1} = \left\{ \frac{1}{\alpha-1} \left(\frac{1}{R \alpha L_2^{(1-\alpha)}} \right)^{[1/(\alpha-1)]-1} \left(\frac{-\alpha L_2^{(1-\alpha)} (dR/dK_1)}{(R \alpha L_2^{(1-\alpha)})^2} \right) \right\} - 1 \quad (\text{A.13})$$

and subbing in the expression for dR/dK_1 from (A.11) gives us

$$\frac{dI_1}{dK_1} = \left\{ \frac{1}{\alpha-1} \left(\frac{1}{R \alpha L_2^{(1-\alpha)}} \right)^{[1/(\alpha-1)]-1} \left(\frac{-\alpha L_2^{(1-\alpha)} \left(\frac{-(\alpha-1)(K_1+I_1)^{\alpha-2}}{\alpha L_2^{(1-\alpha)} (K_1+I_1)^{2\alpha-2}} \right)}{(R \alpha L_2^{(1-\alpha)})^2} \right) \right\} - 1 \quad (\text{A.14})$$

which after some manipulation yields

$$\frac{dI_1}{dK_1} = \left\{ \left(\frac{1}{R\alpha L_2^{(1-\alpha)}} \right)^{[1/(\alpha-1)]-1} \cdot \left[\frac{(K_1 + I_1)^{\alpha-2}}{(R\alpha L_2^{(1-\alpha)})^2 (K_1 + I_1)^{2\alpha-2}} \right] \right\} - 1 \quad (\text{A.15})$$

which is clearly > -1 .

