Disasters and Development: Natural Disasters, Credit Constraints and Economic Growth

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Abstract

We demonstrate, using a simple two-period equilibrium model of the economy, the potential effects of extreme event occurrences - such as natural or humanitarian disasters - on economic growth over the medium- to long-term. In particular, we focus on the effect of such shocks on investment. We examine two polar cases; an unconstrained economy where agents have access to perfect capital markets, versus a credit-constrained version, where the economy is assumed to operate in financial autarky. Considering these extreme cases allows us to highlight the interaction of disaster events and economic underdevelopment, manifested through poorly developed financial markets. The theoretical analysis shows that, where agents face borrowing constraints, the shock of a disaster occurrence could have lasting effects on economic growth.

The predictions of our theoretical model are then tested using a panel of data on natural disaster events at the country-year level, covering the period 1979-2007. We find that for countries with low levels of financial sector development, natural disaster events exert a significant negative impact on economic growth. In particular, where access to credit is problematic, the negative effects of disasters on growth are *persistent* over the medium-term. These results appear to be robust to various checks. Our findings suggest that natural disasters do represent significant threats to economic development in poor countries.

Keywords: natural disasters, financial development, economic growth

JEL Classification: O11; O15; Q54; Q56

1 Introduction

The aim of this paper 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 the context of 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. A recent review of the literature on the economics of natural disasters (Cavallo and Noy, 2009) concludes that the long-term effects of disasters are as yet not well understood. 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. Over the long-term, what matters for economic development is the extent to which extreme events impact on savings and investment decisions.[1]

In this paper, we propose a theoretical model of the investment effects of extreme events such as natural and humanitarian disasters. We present two polar cases - in the unconstrained 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.[2] 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.

To preview the results of the theoretical work briefly, we demonstrate that shocks such as natural disasters are likely to have more significant long-term effects on low-income countries. In particular, where agents face borrowing constraints, a shock to household

[1]Tol and Leek argue that "the 'only' thing that counts ... is how [natural disasters] affect the propensity to save and (re)invest in the affected region." (1999: 311). The accumulation, through investment, of physical and human capital has long been seen as a key driver of long term economic performance. See for example Solow (1956), Lucas (1988) and Mankiw, Romer & Weil (1992).

[2]For a review of the interaction between financial development and poverty or income inequality, see Demirguc-Kunt and Levine (2009).

income results in lower levels of investment, thus reducing potential economic growth over the long-term. The empirical results reported in section 4 would seem to support the predictions of our theoretical model - the availability of credit representing a significant factor in determining the economic impacts of natural disaster events. Furthermore, 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). We find that credit constrained economies are likely to suffer more severe and more *persistent* effects of disasters on economic growth.

The rest of the paper is organized as follows. In section 2 we review the literature on the economic effects of natural disasters. In Section 3 we present our theoretical model and derive results for the effects of natural disaster shocks on investment. In Section 4 we discuss our data and empirical framework and present results of our empirical analysis. Section 5 concludes.

2 Natural disasters, volatility and economic growth

> "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 and Leek, 1999, footnote no.2, p.326)

Natural disasters have often been viewed in the so-called "grey literature" (reports by government and international agencies, NGOs etc.) as a significant barrier to economic development (e.g. UNISDR, 2002). However this view has been criticised in some of the academic (peer-reviewed) 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 and Toya, 2002).[3]

[3] Possible explanations for this positive relationship include a Keynesian type stimulus from reconstruction activity, or a Schumpeterian 'creative destruction' effect. However, the possibility of such a positive productivity effect resulting from an natural disaster occurrence has been disputed by Hallegatte and Dumas (2009), while Crespo Cuaresma et al. (2008) suggest that only developed countries are likely to benefit from any such mechanism. Tol and 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 stocks.

In the more recent literature, however, there appears to be an emerging consensus on the short-run economic impacts of natural disasters (see e.g. Noy, 2009; Raddatz 2007; Loayza et al., 2009). 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 (Loayza et al., 2009). Particularly damaging are "extreme" events such as severe storms and/or flooding, and prolonged periods of drought (Loayza et al., 2009). Such events can overwhelm the coping capacities of the local economy, destroying infrastructure and crops, displacing populations and in some cases leading to disease outbreaks.

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 (World Bank, 2000).[4] 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.[5]

As noted by Auffret (2003), under the general equilibrium framework (Debreu, 1959; Arrow and 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.

Although growth theories have tended to discount the relevance of volatility and shocks for long run economic performance (Lecocq and Shalizi, 2007), 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

[4] As cited in UNISDR (2002).

[5] The literature on the economic effects of natural disasters suggests that weak institutions are associated with more severe impacts. See for example Kahn (2005) and Noy (2009).

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.[6] However, in a seminal contribution, Ramey and 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 and Pinto, 2005). Such indirect impacts of volatility may be particularly deleterious in poor countries with weak 'shock absorbers'.[7]

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.[8]

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) have 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 paper.

The emphasis here on "extreme" events (i.e. natural disasters) is further justified by the findings of Hnatkovska and 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

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

[7] Relevant 'shock absorbers' might include developed financial markets and counter-cyclical fiscal policy (Loayza et al., 2007; see also Tol and Leek, 1999, for a discussion of the importance of insurance and financial reserves in coping with natural disasters).

[8] This point is made in Jacoby and Skoufias (1997). For evidence of this type of behaviour see Scoones et al. (1996) and Rosenzweig and Wolpin (1993).

over the long run. Furthermore, there is an increasing awareness among macroeconomists of the need to take account of the possibility of extreme (rare/unlikely but large) events. This point is made by Cavallo and Noy (2009) and, in a slightly different context, by Krugman (2009).[9] 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).

3 Modelling the Investment Effects of Natural Disaster Events

In this section we present our theoretical model. A simple two-period framework is used to model the macroeconomic impacts of extreme events.[10] The following section sets out the basic properties of the model.[11]

3.1 The basic model

Agents maximize utility

$$U = ln(C_1) + Bln(C_2) \tag{1}$$

subject to

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

where periods are subscripted 1 and 2. The production function F(•, •) is assumed to be at least twice continuously differentiable and to 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 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 for the moment that labour is supplied inelastically, and normalise the labour supply in each period to unity in order to focus exclusively on the investment

[9] As cited by Cavallo and Noy (2009, p.32).

[10] The basic structure of the two-period model follows Barry (1999) who uses such a framework to analyse the macro effects of changes in fiscal policy.

[11] Detailed, step-by-step derivations of results are included in the mathematical appendix.

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.

$$K_2 = K_1 + I_1 \tag{3}$$

Using equation (3) we can rewrite the budget constraint (2) as follows

$$C_1 + RC_2 = F(K_1, L_1) - I_1 + RF(K_1 + I_1, L_2) \tag{4}$$

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

$$C_2 = C_1 \left(\frac{B}{R}\right) \tag{5}$$

and

$$RF_{K2} = 1 \tag{6}$$

Equations (5) and (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 (5).

3.2 An event that destroys a portion of the capital stock

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

$$Y = K^{\alpha} L^{\beta}$$

where α and β represent the capital and labour elasticities respectively, with $\alpha, \beta > 0$ and $\alpha + \beta = 1$, we can rewrite (6) as follows

$$\alpha(K_1 + I_1)^{(\alpha-1)} L_2^{\beta} = \frac{1}{R} \tag{7}$$

giving

$$I_1 = \left(\frac{1}{\alpha L_2^{\beta} R}\right)^{1/(\alpha-1)} - K_1 \tag{8}$$

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

$$\frac{dI_1}{dK_1} = -1 \tag{9}$$

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.

3.3 The case of a credit-constrained economy

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 (7) can be used to express R as follows

$$R = \frac{1}{\alpha(K_1 + I_1)^{(\alpha-1)} L_2^{\beta}} \tag{10}$$

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 (10) with respect to K_1, we have

$$\frac{dR}{dK_1} = \frac{-(\alpha-1)(K_1 + I_1)^{\alpha-2}}{\alpha L_2^{\beta}(K_1 + I_1)^{2\alpha-2}} > 0 \tag{11}$$

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.[12]

Returning to our equation for I_1 from above (equation 8) it is clear that the presence of R in this equation implies that, for the credit-constrained economy, 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 (9) now becomes

$$\frac{dI_1}{dK_1} = \left\{ \left(\frac{1}{R\alpha L_2^{\beta}} \right)^{[1/(\alpha-1)]-1} \cdot \left[\frac{(K_1 + I_1)^{\alpha-2}}{(R\alpha L_2^{\beta})^2 (K_1 + I_1)^{2\alpha-2}} \right] \right\} - 1 \tag{12}$$

which is clearly > -1.[13]

A rising interest rate (in response to the shock) will push dI_1/dK_1 towards zero, or even into positive territory. Thus, for the credit constrained economy, the shock to the capital stock following a natural disaster event is no longer fully compensated by investment.

4 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 in poorer regions, where access to credit is problematic. We test this hypothesis using a comprehensive panel dataset of natural disaster events at the country level, for the period 1979-2007.

4.1 Data

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 period 1960-2009. We focus our analysis on the period 1979-2007 for reasons of data quality and completeness.

[12] Another 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, which shows that poor households are often forced to sell-off productive assets in the aftermath of natural disaster events.

[13] See the mathematical appendix for a step-by-step derivation of this result.

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, this economic data is not considered to be reliable as there is no systematic way of collecting damage cost data in the aftermath of natural disasters. We therefore concentrate on the numbers killed or otherwise affected by disaster events in constructing our measures of natural disasters.

We construct two measures of disaster events for use in our analysis - a continuous measure and a binary measure. The continuous measure is defined as follows:

$$Disaster_{it} = ln\left(1 + \Sigma_j \frac{TotalAffected_{it,j}}{Population_{i,t-1}}\right) \tag{13}$$

where j indexes the number of events recorded in country i in period t. The sum of the total number of people affected by disaster events per country-year observation is normalized by the size of the population of the country in order to facilitate comparison across countries.[14] 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 disaster events (and conditional on there being an event in a given country/year) are included in Table 1. There are 2,123 country/year observations in the data that include at least one disaster event. The average disaster event affects 3.8% of the population. However, the largest observation in the data is over 150% of the population affected by disaster events in a single year (recall that the measure involves the sum of all disaster events in a given country/year). Clearly such large values might be considered 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 population were affected, while in 95% of cases less than 21% of the population were affected. In the analysis reported below, we show that our results gain in significance if we omit the top 1% (or 5%) of the disaster distribution, lending further support to the idea that these large values represent outliers and may be distorting the true effects of disaster

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

events.

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. Climatological events (e.g. droughts and extreme temperatures) 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). Hydrological 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 we construct is a binary measure, which takes a value of 1 if:

$$\Sigma_j \frac{TotalAffected_{it,j}}{Population_{i,t-1}} > 0.005 \tag{14}$$

The motivation for using such a binary measure of disaster events is to reduce the potential endogeneity of the disaster measure with respect to economic development. The effects of disaster events, in terms of the numbers of people killed or affected, are dependent to some extent on various socio-economic factors (see for example Sen, 1981; Kellenberg and 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 disaster events 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 shows the frequency of disaster events that exceed the 0.5% threshold. While 43% of all country/year observations include some reported disaster event, 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. 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. Climatological and meteorological 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 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 we 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).[15] 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 we were forced to omit the

[15] In the results reported below, we 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): "variation in the measure of credit within the $0 - 10\%$ range is unlikely to be informative about the variation in the availability of funds" (p.17). However, our results remain robust to the removal of this restriction, or to variations involving a higher threshold.

affected countries from the current version of our analysis.[16] We thus have a panel dataset with 170 countries, covering the period 1979-2007.[17]

Data on economic growth and income levels come from the Penn World Tables version 6.3 (Heston et al. 2009). Other economic indicators are from the World Bank's World Development Indicators (World Bank, 2010).

Table 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 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. In line with convergence theory, poor countries do grow faster on average over the sample period, although this growth is more volatile.[18]

4.2 Empirical framework

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

$$\Delta y_{it} = \beta_0 + \beta_1 y_{i,t-2} + \beta_2 D_{it} + \beta_3 credit_{i,t-1} + \beta_4 D_{it} * credit_{i,t-1} + \theta_i + \theta_t + \epsilon_{it} \qquad (15)$$

where Δy_{it} represents the annual growth rate of output per capita in country i for period t. A lagged income term ($y_{i,t-2}$, income per capita in logs, lagged two periods) is included to

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

[17]The panel is unbalanced as the credit measure that we use was not available for every country-year in our dataset. As a check on the robustness of the results reported below, we 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. We also tried running all of our 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.

[18]It 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. We might be concerned that our results would be driven by these outliers. To be sure this is not the case, we check the robustness of our results to the exclusion of the top and bottom 1% of the annual growth distribution.

capture convergence effects.[19] Our credit measure (used to proxy for 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.[20]

We interact the credit measure with our 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 disaster events. If our 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 disaster events (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, we include country fixed effects (θ_i) and cluster errors by country. We 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.

We 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.

4.3 Results

4.3.1 Identifying the channels of effect from disasters to economic growth

Table 4 presents results of regressions using the binary measure (=1 if $>$ 0.5% of the population is affected). To begin with we 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 model (2) we include the interaction of our

[19] This 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. We generally found evidence of strong short-term convergence effects in the data, while we also experimented with different lags of income per capita and found our results were robust to these variations in specification.

[20] Variations on our 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.

disaster measure with credit availability (the main focus of our 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 our 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.[21]

Models (3), (4) and (5) include various checks on the robustness of these results. In model (3) we use period average credit, instead of the lagged credit term. This is to confirm that our 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 our findings.

In model (4) we 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 our interaction between disasters and credit remain robust to the inclusion of the poor country dummy.

Finally, in model (5), we 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 not enter significantly in the regression. Interestingly, the disaster measure itself also loses significance in this model.[22] However, the coefficient on

[21] For Burkina Faso, the effect on output growth is: (-1.6117) + (0.0275)*(13) = -1.2542. For the Czech Republic, the effect is: (-1.6117) + (0.0275)*(53) = -0.1542.

[22] The ambiguity of these results may be explained by the counter-vailing effects of agricultural depen-

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 our theoretical model. Where access to credit is problematic, countries suffer more severe output effects from the occurrence of natural disasters.

4.3.2 Using the continuous disaster measures

In Table 5 we present regression results using the continuous measure of disasters, as defined above. When we include the full sample of disaster events 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. We thus 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. The results from these models would seem to suggest that a small number of large outlier events may be distorting the true relationship between disasters and economic growth, when using the full sample and the continuous measure of disaster events.

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.[23] 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 the level of financial development of the Czech

dence 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).

[23]Recall that the continuous disaster measure enters the regression as ln(1 + the % of the population affected).

Republic, would not reduce contemporaneous output growth.[24] Again, the results using the continuous measure would seem to support the predictions of our theoretical model.

4.3.3 Dynamics of disasters: Models with lags

In Table 6 we 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.

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.[25] 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 our sample is 1.07%. Thus for a country with the level of financial development of Burkina Faso, a disaster event would completely wipe out economic growth for up 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.[26] The results suggest that disasters have persistent

[24]For Burkina Faso: (-24.6804)*ln(1 + 0.038) + (13)*(0.4754)*ln(1 + 0.038) = -0.69. For the Czech Republic: (-24.6804)*ln(1 + 0.038) + (53)*(0.4754)*ln(1 + 0.038) = +0.02.

[25]Note 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.

[26]The calculations used to derive these quantitative effects involve: (sum of disaster coefficients) + (sum

as opposed to transitory effects where credit access is problematic, thus supporting the predictions of our theoretical model.

4.3.4 Robustness checks on the model with lags

In this section, we 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 our results might be the potential for serial correlation in the time-series on economic growth. For this reason, we repeat the analysis of the dynamics of disasters and growth using a panel autoregressive distributed lag (PARDL) model. In this model we include lags of growth in the regressions. Results in Table 7 are almost identical to those presented previously, although there is some loss of significance at 10 lags.[27]

In Table 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. We thus repeat the analysis contained in Table 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 8, our results 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.

As mentioned previously, we also repeated our analysis on a dataset that excludes those countries for which complete economic data was not available. The results from this

of interaction term coefficients)*(credit as % of GDP).

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

analysis (not reported) were almost identical to those presented in Table 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). The findings remained qualitatively unchanged (and indeed quantitatively very similar also) for all of these specifications.

5 Summary and Conclusions

In our theoretical analysis, we 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, we 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. We have modelled our 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, we 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 event 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 our model would seem to support the hypothesis that the availability of credit may be a significant factor in determining the economic impacts of natural disaster events. 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).

We 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, we 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. Our findings suggest that natural disasters do represent significant threats to economic development in poor countries.

5.1 Next steps/future research

While the empirical model used here appears to be capable of identifying the kind of effects we are interested in, it may be that this specification is excessively parsimonious, in that the only control variables included are time and country fixed effects and a lagged income measure. It may be interesting to test the robustness of our findings to the inclusion of factors such as Official Development Aid (ODA), terms of trade shocks, policy and structural variables etc. However, the present empirical framework would not be suitable for such an analysis, given the likely endogeneity of at least some of those factors mentioned. A panel VAR model (as used in Raddatz, 2007; 2009) or a system GMM (as used in Levine et al. 2000; and Loayza et al. 2009) would allow for the inclusion of these type of control variables. This we leave to future research.

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MATHEMATICAL APPENDIX

The basic model

Agents maximize utility

$$U = ln(C_1) + Bln(C_2) \tag{16}$$

subject to

$$C_1 + RC_2 = F(K_1, L_1) - I_1 + RF(K_2, L_2) \tag{17}$$

Lagrangian

$$L = ln(C_1) + Bln(C_2) - \lambda[C_1 + RC_2 - F(K_1, L_1) + I_1 - RF(K_1 + I_1, L_2)] \tag{18}$$

$$dL/dC_1 = 1/C_1 - \lambda = 0 \tag{19}$$

$$dL/dC_2 = B/C_2 - \lambda R = 0 \tag{20}$$

$$dL/dI_1 = -\lambda + \lambda RF_{K2} = 0 \tag{21}$$

Giving the first-order conditions

$$C_2 = C_1 \left(\frac{B}{R}\right) \tag{22}$$

$$RF_{K2} = 1 \tag{23}$$

Investment effects in a credit-constrained economy

Assuming a Cobb-Douglas production function, (23) can be rewritten as follows

$$R = \frac{1}{\alpha(K_1 + I_1)^{(\alpha-1)} L_2^{\beta}} \tag{24}$$

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

$$\frac{dR}{dK_1} = \frac{-\alpha(\alpha-1)(K_1+I_1)^{\alpha-2}L_2^{\beta}}{(\alpha[K_1+I_1]^{\alpha-1}L_2^{\beta})^2} \tag{25}$$

which yields, after some simplification

$$\frac{dR}{dK_1} = \frac{-(\alpha-1)(K_1+I_1)^{\alpha-2}}{\alpha L_2^{\beta}(K_1+I_1)^{2\alpha-2}} > 0 \tag{26}$$

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 (23) and using the Cobb-Douglas production function, we have

$$I_1 = \left(\frac{1}{\alpha L_2^{\beta} R}\right)^{1/(\alpha-1)} - K_1 \tag{27}$$

then

$$\frac{dI_1}{dK_1} = \left\{\frac{1}{\alpha-1}\left(\frac{1}{R\alpha L_2^{\beta}}\right)^{[1/(\alpha-1)]-1}\left(\frac{-\alpha L_2^{\beta}(dR/dK_1)}{(R\alpha L_2^{\beta})^2}\right)\right\} - 1 \tag{28}$$

and subbing in the expression for dR/dK_1 from (26) gives us

$$\frac{dI_1}{dK_1} = \left\{\frac{1}{\alpha-1}\left(\frac{1}{R\alpha L_2^{\beta}}\right)^{[1/(\alpha-1)]-1}\left(\frac{-\alpha L_2^{\beta}\left(\frac{-(\alpha-1)(K_1+I_1)^{\alpha-2}}{\alpha L_2^{\beta}(K_1+I_1)^{2\alpha-2}}\right)}{(R\alpha L_2^{\beta})^2}\right)\right\} - 1 \tag{29}$$

which after some manipulation yields

$$\frac{dI_1}{dK_1} = \left\{\left(\frac{1}{R\alpha L_2^{\beta}}\right)^{[1/(\alpha-1)]-1} \cdot \left[\frac{(K_1+I_1)^{\alpha-2}}{(R\alpha L_2^{\beta})^2(K_1+I_1)^{2\alpha-2}}\right]\right\} - 1 \tag{30}$$

which is clearly > -1.

Table 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, Extreme Temp.	407	9.24	18.82	2.25e-06	116.15
Geological	Earthquakes, Volcanoes	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: 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 Population)	16.86%
	> 0.5% of Population Affected	
Biological	Epidemics	0.98%
Climatological	Droughts, Extreme Temp.	5.01%
Geological	Earthquakes, Volcanoes	1.34%
Hydrological	Floods	7.82%
Meteorological	Storms	4.93%

Table 3: Summary statistics: Rich versus poor countries

Variable	Mean	Std. Dev.	Min	Max
Rich				
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
Poor				
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 4: Contemporaneous effects using binary measures

	Dependent variable: Annual growth				
	(1)	(2)	(3)	(4)	(5)
Disaster	-0.9409***	-1.6117***	-1.4863***	-1.7906***	-0.5794
	(-2.86)	(-2.78)	(-2.64)	(-2.92)	(-0.55)
Dis*Credit		0.0275**		0.0293**	0.0210*
		(2.35)		(2.33)	(1.74)
Credit		-0.0157*		-0.0097	-0.0087
		(-1.68)		(-1.16)	(-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-Squared	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 5: Contemporaneous effects: Other measures

	Dependent variable: Annual growth		
	Continuous Measures		
	(1)	(2)	(3)
	All	Excl. top 1%	Excl. top 5%
Disaster	-7.7526	-14.3958**	-24.6804***
	(-1.53)	(-1.99)	(-2.81)
Dis*Credit	0.1300	0.1647	0.4754***
	(1.00)	(1.01)	(3.47)
Credit	-0.0060	-0.0063	-0.0089
	(-0.77)	(-0.80)	(-1.09)
Obs.	3439	3425	3361
Countries	146	146	146
Adj. R-Squared	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 6: Dynamics of disasters and growth: Lagged effects

	Dependent variable: Annual growth				
	(1)	(2)	(3)	(4)	(5)
	No Lags	1 Lag	3 Lags	5 Lags	10 Lags
disasters	-1.5271**	-1.3418	-3.4863**	-3.8557**	-5.6121**
	(-2.33)	(-1.58)	(-2.50)	(-2.11)	(-2.11)
$disaster * credit$	0.0267**	0.0303	0.0675**	0.0799**	0.1147*
	(2.07)	(1.60)	(2.27)	(2.01)	(1.94)
Obs.	3210	3179	3109	2818	2097
Countries	146	146	146	145	141
Adj. R-Squared	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 7: Dynamics of disasters and growth: Including lags of growth

	Dependent variable: Annual growth				
	(1)	(2)	(3)	(4)	(5)
	No Lags	1 Lag	3 Lags	5 Lags	10 Lags
disasters	-1.5271**	-1.2352	-3.5255**	-3.9057**	-5.8917*
	(-2.33)	(-1.55)	(-2.58)	(-2.15)	(-1.87)
disaster ∗ credit	0.0267**	0.0274	0.0668**	0.0797**	0.1144
	(2.07)	(1.54)	(2.27)	(2.01)	(1.60)
Obs.	3210	3179	3109	2815	2094
Countries	146	146	146	145	141
Adj. R-Squared	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 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
disasters	-0.4822	-0.1754	-2.0334	-1.9622	-3.5160*
	(-0.45)	(-0.16)	(-1.65)	(-1.47)	(-1.81)
$disaster * credit$	0.0192*	0.0228	0.06014**	0.0710*	0.1062*
	(1.70)	(1.28)	(2.11)	(1.87)	(1.93)
$disaster * AgriShare$	-0.0374	-0.0451	-0.0609	-0.0790	-0.0810
	(-0.66)	(-0.79)	(-1.02)	(-1.29)	(-1.23)
Obs.	3144	3114	3046	2761	2055
Countries	143	143	143	142	138
Adj. R-Squared	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 for *disasters* and $disasters * credit$ are the summed contemporaneous and lagged effects.

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

$^{*}p < 0.10,^{**}p < 0.05,^{***}p < 0.01$.