DO NATURAL DISASTERS PROMOTE LONG-RUN GROWTH?

MARK SKIDMORE and HIDEKI TOYA*

In this article, we investigate the long-run relationships among disasters, capital accumulation, total factor productivity, and economic growth. The cross-country empirical analysis demonstrates that higher frequencies of climatic disasters are correlated with higher rates of human capital accumulation, increases in total factor productivity, and economic growth. Though disaster risk reduces the expected rate of return to physical capital, risk also serves to increase the relative return to human capital. Thus, physical capital investment may fall, but there is also a substitution toward human capital investment. Disasters also provide the impetus to update the capital stock and adopt new technologies, leading to improvements in total factor productivity. (JEL O11, O15, O57)

I. INTRODUCTION

Risks to life and property exist, in varying degrees, in every country of the world. Numerous studies on the relationship between risk and expected losses and economic decisions are available and generally widely known, but to our knowledge there are no empirical studies that evaluate the effects of natural hazards on long-run economic growth in a macroeconomic framework. Despite the vast empirical literature

*We would like to thank two anonymous referees, William Blankenau, Gerhard Glomm, Hiroyuki Hashimoto, Denton Marks, Yuichi Morita, Masaya Sakuragawa, Etsuro Shioji, and seminar participants at Kansai Macroeconomic Workshop, Macalester College, Midwest Economic Association Annual Meeting, Northern Iowa University, University of Wisconsin-Whitewater, and Yokohama National University for helpful comments and suggestions.

Skidmore: Associate Professor, University of Wisconsin—Whitewater, Whitewater, WI 53190. Phone 1-262-472-1354, Fax 1-262-472-4863, E-mail skidmorm@mail.uww.edu.

Toya: Associate Professor, Nagoya City University, Nagoya, Japan. Phone 81-52-872-5737, Fax 81-52-872 5737, E-mail toya@econ.nagoya-cu.ac.jp

- 1. See, for example, the literature on risk and portfolio choice (Hakansson, 1970; Merton, 1969; Sandmo, 1969), uncertainty related to income variance and savings decisions (Leland, 1969; Sandmo, 1970; Dréze and Modigliani, 1972; Kimball, 1990; Zeldes, 1989; Skinner, 1988; Dynan, 1993; Guiso et al., 1992), insurance and behavioral responses to risk and uncertainty (Kunreuther et al., 1995; Kunreuther, 1996), and economic responses to risks from natural disasters (Brookshire et al., 1985; Skidmore, 2001).
- 2. Barro (1991) empirically examines the related issue of the effects of political instability on economic growth.

that examines the linkages between long-run average growth rates, economic policies, and political and institutional factors, the relationship between disaster risk and long-run growth has not been empirically examined.

There is, however, a body of research that has examined the effects of natural disasters on economic variables in the short run. Tol and Leek (1999) provide a summary of the recent studies that assess the immediate repercussions of natural disasters on economic activity. The empirical findings in this literature (Albala-Bertrand, 1993; Dacy and Kunreuther, 1969; Otero and Marti, 1995) report that gross domestic product (GDP) is generally found to increase in the periods immediately following a natural disaster. This result is due to the fact that most of the damage caused by disasters is reflected in the loss of capital and durable goods. Because stocks of capital are not measured in GDP and replacing them is, GDP increases in periods immediately following a natural disaster.

Our article extends the short-run analysis by examining the possible linkages among disasters, investment decisions, total factor productivity, and long-run economic

ABBREVIATIONS

CRED: Center For Research on Epidemiology of Disasters

GDP: Gross Domestic Product GNP: Gross National Product

growth. Because disaster risks differ substantially from country to country, it is reasonable to question whether there exists some relationship between disasters and long-run macroeconomic activity. On cursory examination, one might conclude that a higher probability of capital destruction due to natural disasters reduces physical capital investment and therefore curtails long-run growth. However, such analysis is only partial and may be misleading. Disaster risk may reduce physical capital investment, but disasters also provide an opportunity to update the capital stock, thus encouraging the adoption of new technologies.

Furthermore, an endogenous growth framework also suggests that disaster risk could potentially lead to higher rates of growth. In this type of model individuals invest in physical and human capital, but there is a positive externality associated with human capital accumulation. If disasters reduce the expected return to physical capital, then there is a correspondingly higher relative return to human capital. The higher relative return to human capital may lead to an increased emphasis on human capital investment, which may have a positive effect on growth.

We present some initial evidence regarding the relationship between disasters and economic growth in Figures 1 through 4. These figures show the simple relationship between the number of natural disasters and long-run economic growth using a sample of 89 countries. The vertical axis represents the average annual growth rate of per capita GDP over the 1960–90 period. Data on per capita GDP are taken from Summers and Heston (1994). Along the horizontal axes are four different measures of the propensity for natural disasters. The disaster data in Figures 1 and 3 are historical information from Davis (1992) covering 190 years of the world's worst recorded natural disasters. Figures 2 and 4 represent more current and detailed information on natural disasters events for the period 1960 through 1990 from the Center for Research on the Epidemiology of Disasters (CRED) (EMDAT, 2000). Figures 1 and 2 show the natural log of one plus the total number of disaster events from Davis and CRED, respectively.³

3. We take the log of the disaster variables to linearize the relationship between these variables and the

However, because larger countries may be subject to more disasters, we present the natural log of one plus the number of disasters normalized by land area from Davis and CRED in Figures 3 and 4. All of the figures indicate a clear positive association between the number of disasters and economic growth.

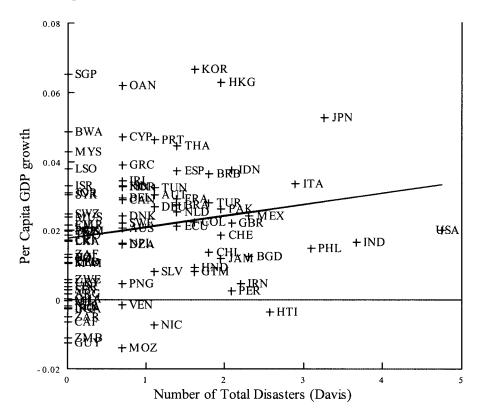
As shown in Table 1, a semilogarithmic regression equation yields a positive and statistically significant relationship between number of disasters and economic growth, explaining as much as 9% of the variation in the growth of per capita GDP. In this simple regression, both the historical disaster measures from Davis (1992) and the recent disaster measures from EMDAT (2000) are significantly correlated with economic growth. These findings are consistent whether we use total disasters or disasters normalized by land area.

In the remainder of this article, we use cross-country variation in natural disasters to estimate their effects on human capital accumulation, physical capital investment, total factor productivity, and economic growth. We demonstrate that the statistical relationship between disasters and economic growth is robust to the inclusion of control variables typically considered important determinants of growth (such as initial income, initial secondary schooling, fertility rate, investment to GDP ratio, trade openness, population, latitude, and a tropics dummy variable). The empirical results also show that climatic disasters are correlated with higher rates of human capital investment and increases in total factor productivity. However, we find no significant correlation between disasters and long-term physical capital accumulation.

In the following section, we present historical and current information on disasters around the world. In section III, we present extensive empirical evidence regarding the relationship between natural disasters and long-run economic growth. In section IV we propose several hypotheses and identify the routes through which disasters affect growth. Finally, we offer our concluding remarks in section V.

dependent variables. Also, because several countries do not experience any significant disasters, we add one so that we can take the log of the variables without arithmetic error.

FIGURE 1
Relationship between the Number of Historical Disasters and Economic Growth



II. DISASTERS AND RISK TO LIFE AND PROPERTY

International Differences in Natural Disasters

Although the potential for natural disasters exists nearly everywhere, exposure to catastrophes varies significantly around the world. For example, Jones (1981) compiles data on disasters and finds that a person living in Asia is about 30 times more likely to die in a seismic disaster than one living in Europe. Similarly, Alexander (1993) shows that most hurricanes occur within the tropics between latitudes 30° N and S, but not within ±5° of the equator, where atmospheric disturbances tend to be insufficient to cause them.

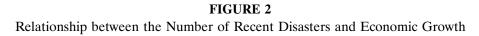
Although death tolls vary from year to year, major disasters kill about 140,000 annually worldwide. In Table 2, we present deaths caused by various types of natural disasters

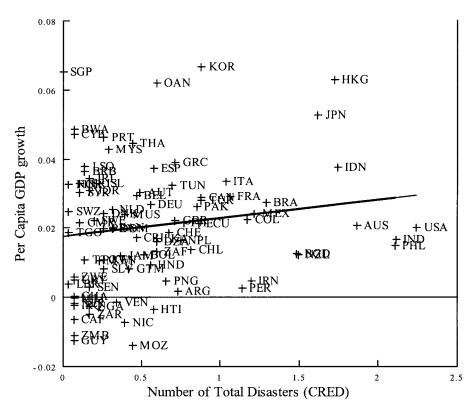
This calculation is, of course, based on very imprecise data because tallies on deaths and damages was not always compiled.

by continent. About 95% of the deaths occur in developing countries, but natural catastrophes also have severe impacts on highly developed countries. For example, the occurrence of both geologic and climatic disasters in Japan, Italy, and the United States make these countries particularly vulnerable. According to Alexander (1993), in the United States 30 disasters are declared in an average year, of which floods account for about 40% of property damage and hurricanes and other tropical storms yield 20% of all disasterrelated fatalities (Alexander, 1993). As shown in Table 2, Asia is affected most severely by natural disasters both in terms of the number of events and deaths.

Historical Evidence on Natural Disasters

Historically, recovery from extreme disasters, such as region-wide famine caused by severe drought, has been very slow. Capital and working animals were lost and,





perhaps more important, skills disappeared with death and outmigration of craftsmen. Full recovery from a severe famine might take as long as 25 years.⁵ Before the Industrial Revolution, the impact of natural disasters on capital accumulation among the poor was negligible. The poor built shelters that were expendable and could easily be replaced. However, in disaster-prone regions the wealthy, ignorant of engineering principles, spent enormous sums of money to overdesign their structures to withstand forces well in excess of the likely forces (Alexander, 1993).

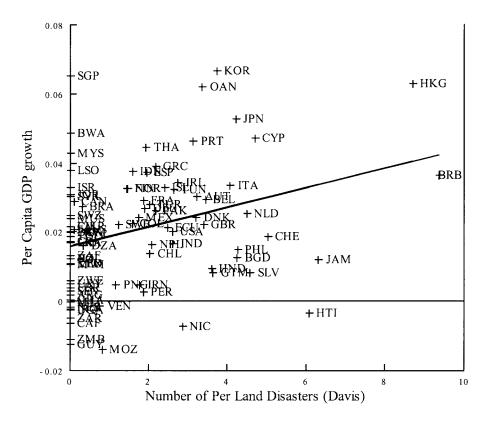
Despite the improvements of engineering and construction, the potential for capital destruction is enormous. For example, in 1992 Hurricane Andrew caused damages in southern Florida and Louisiana exceeding \$20 billion, but due to effective forecasting and evacuation procedures,

5. This section draws heavily from Alexander (1993).

only 13 deaths occurred. Japan is highly susceptible to both climatic and geologic natural disasters. The Tokyo area, home to about one-fifth of Japan's population, is in the vicinity of several plate tectonic faults and is especially vulnerable to seismic activity. Shaw (1994) estimates the cost of an earthquake in the Tokyo area equivalent in magnitude to the Great Kanto earthquake of 1923 to be as much as \$1.2 trillion. Given that a large earthquake is estimated to occur every 60 years, a disaster of enormous consequence

6. \$1.2 trillion is roughly one-fifth of the Japanese GDP. To provide a frame of reference, the estimated losses from the Kobe earthquake were \$114 billion or about one-tenth of the estimated effect of a quake of similar magnitude in Tokyo. Kobe's population is roughly one-fifth of Tokyo's more than 8 million people. If economic losses are proportional to population size, then a quake in Tokyo of similar magnitude would yield losses of about \$570 billion, or about half of Shaw's estimate. But Yokohama (with a population of 3.3 million) and the highly populated area surrounding Tokyo would also be affected.

FIGURE 3
Relationship between the Number of Historical Disasters per Land Area and Economic Growth



could be imminent. These two examples provide some indication of the enormous potential that exists for disaster-induced capital destruction.

Measuring Disasters

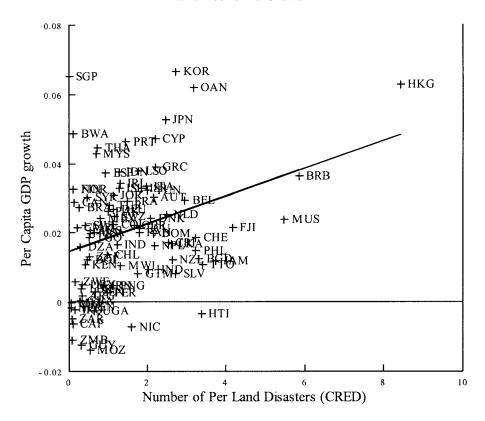
There are many types of potential hazards and the probabilities that these events will occur differ substantially across countries. Although the potential hazards are abundant, we focus on climatic disasters and geologic disasters. In this study, we use two sources of data on natural disasters.

First, historical data on natural disasters come from Davis (1992), who compiles information on the world's worst natural disasters. Some constraints were made in compiling and including natural disasters into our analysis. Davis made an attempt to document all natural disasters through history, but we only include those disasters that occurred

within the last 190 years (1800 through 1990). Davis defines the world's worst natural disasters according to both scientific and subjective criteria. Davis made several subjective judgments before including a natural disaster in his compilation.7 For example, a volcanic eruption of enormous magnitude might be classified by scientific measures as a serious disaster. However, if the eruption were to occur on a remote and sparsely inhabited island, it would not kill many people and destruction of physical capital would be limited. But if the eruption were to occur near a populated city, serious damage would result. There is then a potential that growth would lead to more and greater population centers and thus a greater likelihood that Davis would record the event. However, countries that experience relatively high growth are

^{7.} See Davis (1992) for a more detailed description of his analysis.

FIGURE 4
Relationship between the Number of Recent Disasters per Land Area and Economic Growth



better able to take precautionary steps so that the magnitude of human suffering is less, reducing the likelihood that an event would be recorded. Were it not for the fact that most of the disasters in the Davis data set occurred prior to the period of analysis, causality between disasters and growth would be in

TABLE 1
Growth and Natural Disasters: Dependent Variable: Per Capita GDP Growth (1960–1990 Average)

| Disaster Variable | Constant | Disaster Coefficient | No. of Observations | Adjusted R ² |
|-----------------------------|--------------------|-------------------------|------------------------|-------------------------|
| (1) Total disaster_Davis | 0.0176 (7.1891) | 0.0033 (1.8293) | 89 | 0.0243 |
| (2) Per land disaster_Davis | 0.0158 (6.9249) | 0.0028 (2.7873) | 89 | 0.0941 |
| (3) Total disaster_CRED | 0.0176 (6.0925) | 0.0053 (1.4917) | 89 | 0.0144 |
| (4) Per land disaster_CRED | 0.0145 (5.3599) | 0.0040 (3.1146) | 89 | 0.0953 |

Note: Numbers in parentheses are t values based on the White (1980) heteroskedasticity-consistent covariance matrix.

| Agent | No. of Events | Asia | Oceania | Africa | Europe | South America | Caribbean and Central America | North America |
|-------------------------|------------------|-----------|---------|--------|--------|------------------|----------------------------------|------------------|
| Earthquake | 180 | 354,521 | 18 | 18,232 | 7750 | 38,837 | 30,613 | 77 |
| Tsunami | 7 | 4459 | _ | _ | _ | _ | _ | 60 |
| Volcanic eruption | 18 | 2806 | 4000 | _ | 2000 | 440 | 151 | 34 |
| Flood | 333 | 170,664 | 77 | 3891 | 11,199 | 4396 | 2575 | 1633 |
| Hurricane | 210 | 478,574 | 290 | 864 | 250 | _ | 16,541 | 1997 |
| Tornado | 119 | 4308 | _ | 548 | 39 | _ | 26 | 2727 |
| Severe storm | 73 | 22,008 | _ | 5 | 146 | 205 | 310 | 303 |
| Fog | 3 | _ | _ | _ | 3550 | _ | _ | _ |
| Heat wave | 25 | 4705 | 100 | _ | 340 | 135 | _ | 2190 |
| Avalanche | 12 | 335 | _ | _ | 340 | 4350 | _ | _ |
| Snowfall & extreme cold | 46 | 7690 | 17 | _ | 2780 | _ | 200 | 2510 |
| Landslide | 33 | 4021 | _ | _ | 300 | 912 | 260 | _ |
| Total | | 1,054,090 | 4504 | 23,540 | 28,694 | 49,275 | 50,676 | 11,531 |

TABLE 2
Loss of Life by Disaster Type and by Continent, 1947–80 (Shah, 1983)

question. However, given that population and economic centers 100-200 years ago were significantly different than they are for the 1960-90 period, Davis's recording of natural disaster events is not systematically biased toward high-growth countries over the 1960-90 period. One advantage of using historical data is that it is arguably exogenous to recent changes in capital accumulation, total factor productivity, and economic growth. We interpret past events as affecting the cultural mindset such that these experiences affect capital accumulation decisions as well as the adoption of new technology. Although the disaster data from Davis (1992) are somewhat crude measures of disaster risk, they should provide an adequate initial estimate of the possible relationships among disasters, investment decisions, total factor productivity, and long-run growth.

We also use a second data set from CRED at the Universite Catholicque de Louvain in Brussels, Belgium (EMDAT, 2000). CRED has compiled data on the occurrences and effects of mass disasters in the world from 1900 to the present. CRED makes a concerted effort to validate the contents of the database by citing and cross-referencing sources. CRED also uses specific criteria for determining whether an event is classified as a natural disaster. The database includes

information on number of events, damages, numbers affected, and deaths. However, we are reluctant to use data on damages, number affected, and deaths for three reasons. First, data on these factors are not always available. Therefore, an estimation procedure must be used to generate predicted values to be used in place of the missing data. However, such a procedure only provides estimates for the missing data. More important, because total damages increase with income, the damages caused by disasters may be endogenously determined. Similarly, numbers of people affected fall with income, so that low-income countries experience more human casualties and losses. Wealthy countries clearly spend more money on safety in terms of building codes, engineering, and other safety precautions, thereby reducing deaths. On the other hand, wealthy countries also have far more physical capital at risk should a natural event occur, increasing the possible damages.⁹ Finally, as noted by Albala-Bertrand (1993), the impacts of disasters are sometimes exaggerated in developing countries to secure international assistance. Thus, data on damages and loss of life are to some degree unreliable.

In our analysis we use the total number of significant events occurring in a country over the 1960–90 period because we believe natural events are the best exogenous measures of disaster risk available. Whether or

^{8.} The reasons for taking into account a disaster are: (1) 10 or more people were killed; (2) 100 or more people were affected/injured/homeless; (3) significant damages were incurred; or (4) a declaration of a state of emergency and/or an appeal for international assistance was made.

^{9.} See Toya and Skidmore (2002) for empirical evidence on the relationship between the level of development and the effects of natural events.

| TABLE 3 |
|---|
| Growth and Natural Disasters: Dependent Variable: Per Capita GDP Growth |
| (1960–1990 Average) |

| Disaster Variable | Constant | Disaster Coefficient | No. of Observations | Adjusted R ² |
|-----------------------------|--------------------|-------------------------|------------------------|-------------------------|
| (1) Total climatic_Davis | 0.0171 (7.6644) | 0.0051 (2.1629) | 89 | 0.0583 |
| (2) Total geologic_Davis | 0.0210 (8.9530) | -0.0010 (-0.4083) | 89 | -0.0099 |
| (3) Per land climatic_Davis | 0.0158 (7.6191) | 0.0034 (3.1876) | 89 | 0.1325 |
| (4) Per land geologic_Davis | 0.0216 (9.6686) | -0.0017 (-1.1764) | 89 | 0.0014 |
| (5) Total climatic_CRED | 0.0178 (6.6683) | 0.0062 (1.5149) | 89 | 0.0174 |
| (6) Total geologic_CRED | 0.0196 (7.6491) | 0.0049 (0.7470) | 89 | -0.0055 |
| (7) Per land climatic_CRED | 0.0154 (6.1871) | 0.0040 (3.1154) | 89 | 0.0918 |
| (8) Per land geologic_CRED | 0.0180 (7.3708) | -0.0044 (-1.6078) | 89 | 0.0310 |

Note: Numbers in parentheses are t values based on the White (1980) heteroskedasticity-consistent covariance matrix.

not a country experiences a natural event does not depend on its level of development. For example, an industrialized country like Japan is located along several plate tectonic fault lines and is therefore subject to frequent earthquakes. However, a developing country like the Philippines is also subject to frequent earthquakes. Other countries (like Sweden) happen to be located in the center of a tectonic plate, so that it rarely experiences seismic activity. Therefore, the number of natural events a country experiences does not depend on its level of development.¹⁰ In the remainder of this article we focus on the total number of natural events normalized by land area because larger countries generally experience more natural disasters. However, using the unadjusted total number of natural events yields qualitatively similar results. We use both the historical data covering the period 1800–1990 from Davis (1992) and data from EMDAT (2000) covering the period 1960–90. Summary statistics for these and all other variables used in our analysis are presented in Appendix C. Appendix A provides definitions

10. Over an extended period of time, frequency of natural disasters may affect migration patterns.

and sources for all variables used in the analysis.

We also separate climatic from geologic disasters because the relative effects of each on the economic decisions may differ. In Table 3 we present a series of regressions to demonstrate the importance of considering climatic and geologic disasters separately.¹¹ The simple regressions show that climatic disasters are positively correlated with economic growth, whereas geologic disasters are negatively correlated with growth but not always statistically significant. Climatic disasters tend to occur more frequently and during a particular time of the year. In addition, forecasting makes it possible for agents to protect themselves by taking cover or evacuating the afflicted region. Therefore, agents may perceive climatic disasters as primarily a threat to property and not life. We suggest that climatic disasters are a reasonable proxy for risk to physical capital. In contrast, geologic disasters are less frequent and, given

11. In our empirical study, climatic natural disasters include floods, cyclones, hurricanes, ice storms, snow storms, tornadoes, typhoons, and storms. Geologic disasters include volcanic eruptions, natural explosions, avalanches, landslides, and earthquakes.

the current state of technology, forecasting ability is poor. Thus, earthquakes may be perceived as a threat to both life and property. For these reasons, in the remainder of the article we disaggregate climatic and geologic disasters, including both variables in our empirical analysis.

Finally, we assume that citizens are aware of the inherent risks associated with location.¹² For example, the probability of an earthquake in Sweden, as noted, is virtually zero, but countries along the Mediterranean Sea or along the Pacific Rim are far more likely to experience an earthquake because they are located on seismic fault lines.¹³ We assert that agents generally comprehend disaster risk and the economic implications for the region in which they live.

III. EMPIRICAL EVIDENCE

Disasters and Long-Run Economic Growth

We begin our more rigorous empirical analysis by estimating a number of growth regressions that include a wide range of control variables considered important determinants of growth in past studies. As shown in Table 4, controlling for initial 1960 per capita GDP, initial 1960 educational attainment, the fertility rate, the average ratio of real domestic investment to real GDP for the 1960-90 period, the ratio of government consumption spending to real GDP, and the ratio of imports plus exports to real GDP, a semilogarithmic regression equation fits the data very well, explaining about 56% of the variation in the growth of per capita GDP.

The estimates presented in Table 4 come from a 1960 through 1990 cross-section of

12. Some studies show that risk from natural disasters can have a substantial effect on economic activity. For example, Brookshire et al. (1985) use data on home sales in Los Angeles and San Fransisco areas to estimate the effects of home proximity to plate tectonic fault lines on home prices. Holding other factors constant, their results indicate that close proximity to a fault hazard zone reduces home values in the Los Angeles area by \$4650 (in 1978). This study provides evidence that home buyers in California use well-publicized information on earthquake hazards to ascertain property values, and they do so in a way that is consistent with the expected utility framework.

13. Fault lines exist at the meeting of two or more tectonic plates. Earthquakes are far more likely along plate tectonic boundaries. For example, Japan lies along several fault lines, making the entire country susceptible

to frequent earthquakes.

89 countries (the largest number of countries that we have been able to assemble data for the variables employed). All regressions are estimated using an ordinary least squares procedure with White's (1980) correction to ensure heteroskedastic-consistent standard errors. Appendix A shows the list of variables and sources, and Appendix B provides the list of countries in the sample. We present summary statistics of all variables in Appendix C.

Following recent studies of the determinants of economic growth using crosssectional data, we begin with a specification in which the average annual growth rate of real per capita GDP is regressed on the variables mentioned and on the measures of disasters.¹⁴ Consistent with previous work, all of the control variables have statistically significant effects on economic growth. Countries with lower initial levels of income grow at faster rates, as do countries with higher levels of initial human capital. Similarly, lower levels of fertility, higher levels of investment, lower government consumption spending, and increases in trade flows increase economic growth. In this initial specification, the historical disaster measures (Davis, 1992) and the recent disaster measures (EMDAT, 2000) have significant effects on economic growth. The climatic disaster variables are positively correlated with economic growth, whereas the historical geologic disasters are negatively associated with economic growth. However, the current measure of geologic disasters from EMDAT (2000) is statistically insignificant. These results are consistent and robust whether we use total disasters or disasters normalized by land area. 15 Note that the adjusted R^2 increases when the disaster variables are included in the regressions.

Robustness

One might argue that the observed correlation between disasters and growth is spurious. For example, it may be that small

14. See Barro (1991), Benhabib and Spiegel (1994), Levine and Renelt (1992), Mankiw et al. (1992), and Temple (1999) for a review of recent empirical studies on economic growth.

15. In estimates that are not presented but are available on request, we test climatic and geologic disasters separately. These results are similar to those presented

TABLE 4
Growth and Natural Disasters with Additional Control Variables: Dependent Variable: Per Capita GDP Growth (1960–1990 Average)

| Variable | (1) | (2) | (3) | (4) | (5) |
|------------------------------------|---------------------|---------------------|---------------------|----------------------|---------------------|
| Constant | 0.1419 (5.2918) | 0.1253 (5.0095) | 0.1234 (5.1400) | 0.1350 (4.9997) | 0.1261 (4.8842) |
| Log of initial income | -0.0152 (-5.5517) | -0.0141 (-5.7541) | -0.0140 (-5.9852) | -0.0150 (-5.3621) | -0.0149 (-5.6751) |
| Log of initial secondary schooling | 0.0031 (2.5620) | 0.0030 (2.5710) | 0.0029 (2.5655) | 0.0025 (2.0569) | 0.0025 (2.1552) |
| Fertility | -0.0044 (-2.7299) | -0.0031 (-1.8195) | -0.0028 (-1.6080) | -0.0043 (-2.6223) | -0.0033 (-2.0997) |
| Investment | 0.1118 (4.6113) | 0.1184 (4.7466) | 0.1250 (5.0538) | 0.1150 (4.4694) | 0.1372 (5.4839) |
| Government consumption | -0.0699 (-2.0687) | -0.0674 (-1.9550) | -0.0650 (-1.8784) | -0.0654 (-1.9556) | -0.0591 (-1.8949) |
| Trade | 0.0074 (2.4151) | 0.0070 (2.5614) | 0.0038 (1.3447) | 0.0085 (2.6300) | 0.0035 (0.9621) |
| Total climatic_Davis | | 0.0046 (2.9380) | | | |
| Total geologic_Davis | | -0.0044 (-2.1617) | | | |
| Per land climatic_Davis | | | 0.0022 (3.5224) | | |
| Per land geologic_Davis | | | -0.0032 (-2.7725) | | |
| Total climatic_CRED | | | | 0.0054 (1.7833) | |
| Total geologic_CRED | | | | -0.0029 (-0.5995) | |
| Per land climatic_CRED | | | | | 0.0033 (2.9821) |
| Per land geologic_CRED | | | | | -0.0011 (-0.9389) |
| No. of observations | 89 | 89 | 89 | 89 | 89 |
| Adjusted R^2 | 0.5622 | 0.5921 | 0.6155 | 0.5668 | 0.5945 |

Note: Numbers in parentheses are t values based on the White (1980) heteroskedasticity-consistent covariance matrix.

countries have grown more quickly (slowly) so that disasters normalized by land area yield a spurious correlation between disasters and growth. We control for the size of the country by including a measure of land area in the regressions. Perhaps countries with larger populations or greater levels of urbanization are more likely to experience disasters. We control for these characteristics as well. The frequency of disasters may also be partly determined by geographical factors. For example, the likelihood of climatic disasters, such as floods, cyclones, hurricanes,

and typhoons, is much greater in tropical or subtropical regions. Several recent empirical studies show that geographical factors have statistically significant effects on economic growth. Thus, we include a country's distance from the equator as measured by the degree of absolute latitude, and the fraction representing the approximate proportion of

16. Sachs and Warner (1997) show that tropical climate is negatively associated with growth. Hall and Jones (1996) and Ram (1997) empirically show that the distance from the equator is positively related to labor productivity or economic growth.

land area subject to a tropical climate to control for these factors. It is also possible that the coefficients on the disaster variables are picking up continent–geography type effects not otherwise controlled for in our regression analyses. We therefore include several continent dummy variables as defined in the Barro and Lee (1994) data set to control for continent-specific factors. Table 5 demonstrates that when we incorporate any of these characteristics into the analysis, the statistical significance of the disaster variables is maintained.¹⁷

It is well known that Japan and Southeast Asian nations have experienced a remarkable growth rate over the period of our analysis. Many of these countries also experience frequent natural disasters. Thus, our findings may be driven by a spurious correlation between disasters and growth in these Asian countries. It is therefore important to examine whether our findings are robust to the exclusion of these countries. In a series of regressions not presented that exclude different sets of Asian and "ring of fire" countries, we show that the coefficients on the natural disasters variables are similar in magnitude and significance to those presented in this article.18

Also, Sachs and Warner (1997) show that growth is inhibited in landlocked countries

17. The estimated coefficients on the various measures of disasters are robust even when we control for other variables that influence economic growth. In regressions not presented we include the average annual inflation rate over the 1960–89 period and the black market premium for the 1975–79 period. Though these variables are statistically significant and including them improve adjusted R^2 , the coefficients on the disaster variables qualitatively similar to those presented.

18. We estimate three sets of regressions. First we exclude five high-growth East Asian countries (Hong Kong, Japan, Korea, Singapore, and Taiwan). These results show that the coefficients on the natural disaster variables maintain their statistical significance, although the coefficient on total climatic disasters (CRED) is not significant. Next, we exclude a larger set of eight high-growth Asian countries (Hong Kong, Indonesia, Japan, Korea, Malaysia, Singapore, Thailand, and Taiwan) from the analysis. Again, with the exception of the coefficient on total climatic disasters (CRED), the results are similar to those presented in the article. Finally, we exclude all 19 countries considered by the U.S. Geological Survey to be in the "ring of fire" (Canada, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Honduras, Indonesia, Japan, Malaysia, Mexico, New Zealand, Nicaragua, Panama, Papua New Guinea, Peru, Philippines, and the United States). These results are similar to the original findings both in sign and statistical significance. These results are available on request from the author.

without navigable access to sea. Because these countries are not near the ocean, they are not subject to as many violent storms, and so on. Thus, there may again be a spurious correlation between slow-growth countries and absence of disasters. In regressions not presented we exclude all landlocked countries, and again our disaster coefficients maintain their statistical significance.

To summarize, the regression analysis reveals a robust correlation between disasters and long-run economic growth. In the following section we attempt to identify the routes through which disasters affect growth. We demonstrate that the positive relationship between climatic disasters and growth is the result of improvements in technology and increased human capital investment spurred on by climatic disasters. However, the negative and sometimes statistically significant relationship between economic growth and geologic disasters may be an indication that geologic disasters result in loss of life (human capital destruction) along with physical capital destruction so that the net effect on economic growth is negative.²⁰

IV. IDENTIFYING THE ROUTES THROUGH WHICH DISASTERS AFFECT GROWTH

A number of theoretical issues must be considered in our evaluation of the routes though which natural disaster risk affects economic growth. There is a body of literature on the effects of risk on economic behavior as well as determinants of economic growth. We draw on this work to form the hypotheses that we test empirically.

Growth Accounting Approach

We begin our analysis by presenting a basic growth equation. Let y_t denote total output per capita at time t, h_t is the level of per capita human capital, and k_t is the per capita capital stock. The Cobb-Douglas production function is

$$(1) y = A_t k_t^a h_t^{1-a},$$

19. Landlocked countries are Austria, Bolivia, Botswana, Central African Republic, Democratic Republic of the Congo, Jordan, Lesotho, Malawi, Mali, Nepal, Niger, Paraguay, Swaziland, Switzerland, Uganda, Zambia, and Zimbabwe.

20. It is also conceivable that geologic disasters could lead to emigration of the population.

TABLE 5
Growth and Natural Disasters: Robustness Tests; Dependent Variable: Per Capita GDP Growth (1960–1990 Average)

| | • | | ` | 0 / | | |
|-------------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| Variable | (1) | (2) | (3) | (4) | (5) | (6) |
| Per land climatic_Davis | 0.0017 (2.3571) | | 0.0021 (3.9077) | | 0.0022 (3.4675) | |
| Per land geologic_Davis | -0.0034 (-2.8839) | | -0.0032 (-3.0591) | | -0.0033 (-2.8226) | |
| Per land climatic_CRED | | 0.0030 (2.2692) | | 0.0034 (3.2892) | | 0.0032 (2.8320) |
| Per land geologic_CRED | | -0.0011 (-0.8933) | | -0.0011 (-0.8722) | | -0.0010 (-0.8334) |
| Log of land area | -0.0017 (-1.6553) | -0.0004 (-0.3522) | | | | |
| Log of population | | | 0.0018 (2.3221) | 0.0021 (2.2070) | | |
| Log of urbanization | | | | | -0.0018 (-0.6203) | -0.0008 (-0.2632) |
| No. of observations | 89 | 89 | 89 | 89 | 89 | 89 |
| Adjusted R ² | 0.6243 | 0.5899 | 0.6257 | 0.6107 | 0.6136 | 0.5899 |
| | (7) | (8) | (9) | (10) | (11) | (12) |
| Per land climatic_Davis | 0.0017 (2.6888) | | 0.0018 (3.3335) | | 0.0013 (2.1423) | |
| Per land geologic_Davis | -0.0026 (-2.3019) | | -0.0025 (-2.4182) | | -0.0026 (-3.0851) | |
| Per land climatic_CRED | | 0.0028 (2.4672) | | 0.0029 (3.0623) | | 0.0027 (3.0701) |
| Per land geologic_CRED | | -0.0002 (-0.1417) | | 0.0000 (0.0310) | | -0.0024 (-2.0012) |
| Latitude | 0.0003 (2.4423) | 0.0003 (3.3505) | | | | |
| Tropics | | | -0.0109 (-3.4886) | -0.0128 (-4.1651) | | |
| Sub-Saharan Africa | | | (3.4000) | (4.1031) | -0.0126 (-2.5144) | -0.0119 (-2.6172) |
| Latin America | | | | | -0.0101 (-2.2819) | -0.0105 (-2.3276) |
| NIES and ASEAN | | | | | 0.0108 (2.1208) | 0.0132 (2.4459) |
| OECD | | | | | -0.0025 (-0.5346) | -0.0002 (-0.0426) |
| No. of observations | 89 | 89 | 89 | 89 | 89 | 89 |
| Adjusted R ² | 0.6395 | 0.6403 | 0.6721 | 0.6760 | 0.7141 | 0.7069 |

Notes: Numbers in parentheses are t values based on the White (1980) heteroskedasticity-consistent covariance matrix. Other explanatory variables used in Table 4 are included but not reported here.

where A is a coefficient that represents the level of technology. Transforming this function into a growth equation yields

(2)
$$\dot{y}_t/y_t = \dot{A}_t/A_t + a(\dot{k}_t/k_t) + (1-a)(\dot{h}_t/h_t).$$

From equation (2) it is apparent that if disasters have any effect on long-run growth, the route is primarily indirect. That is, disaster risk could be an important factor in investment decisions and the adoption of new technology.

We begin our discussion with physical capital investment, which is perhaps the first factor that comes to mind when one considers the potential effects of natural disaster events on economic activity. Disaster risk lowers the expected return to physical capital, reducing physical capital investment. However, there are several positive routes through which disasters could affect physical capital investment. Because disaster-prone areas are likely to use some of the limited resources for disaster management (stronger and betterengineered structures for example), we might expect a higher level of investment to meet these needs (Tol and Leek, 1999). There is also a rebuilding process in the wake of a disaster so that physical capital investment increases in the periods immediately following a disaster. As we discuss later, a lower expected return to physical capital could lead to increases in human capital. Enhancement of human capital coupled with a human capital externality may lead to increases in the return to physical capital and thus encourage physical capital investment. The net effect of disaster risk on physical capital investment is therefore theoretically ambiguous.

We now consider human capital accumulation. According to endogenous growth theory first introduced by Lucas (1988) and Azariadis and Drazen (1990), human capital is an important key to economic growth. In this framework, individuals invest in physical and human capital, and the aggregate stock of human capital accumulated by previous generations has a positive intergenerational externality on the aggregate level of human capital of succeeding generations. This intergenerational externality is the driving force of growth and is implicitly assumed in a number of growth models in which human capital

is the key determinant of growth.²¹ Consider the case where human and physical capital are substitutable. Increased risk of capital destruction lowers the expected return to physical capital, making human capital relatively more attractive.²² If agents respond by increasing human capital investment, \dot{h}_t/h_t , the emphasis on human capital together with the human capital externality could lead to a higher rate of economic growth.

Natural disasters also have positive longrun economic effects because disasters may encourage the adoption of new technology, as represented by \dot{A}_t/A_t in equation (2). The coefficient A in equation (1) determines how much output can be produced with any given combination of human and physical capital and thus embodies the institutional setting, political climate, the state of technology, and so on. It is conceivable that disasters provide an opportunity to update capital stock and so alter A. Similarly, living in disaster-prone areas may foster adaptability so that new technology is more likely to be embraced as it becomes available in a country. In addition, because human capital is an important component in the adoption of new technologies (Benhabib and Spiegel, 1994), the rate of technological advancement might be enhanced, particularly for developing countries in the process of catch-up.

Insurance and Government Assistance

The degree to which agents bear risk is crucial to this analysis. For agents to respond in the ways previously discussed (in particular for physical and human capital investment decisions), they must believe that they bear at least some of the risk. Insurance is available for many types of risk, so we must examine the role of insurance in disaster mitigation. Although many risks are insurable, some types of risk are either uninsurable or insurance is unavailable at a price agents

^{21.} For example, if, in the Lucas (1988) model, the infinitely lived representative agent is interpreted as a family consisting of finitely lived agents, no growth would arise without assuming some kind of intergenerational externality

^{22.} Of course, natural disasters are also a risk to life and thus also lower the expected return to human capital investment. However, human capital destruction (death) is a far less likely result than loss of physical capital. Therefore we expect the risks to physical capital to dominate the risks to life.

are willing to pay. For frequently occurring disasters, such as auto accidents or fire, it is possible to estimate risks precisely. However, calculating the risks of low-probability-highconsequence events, such as earthquakes and hurricanes, is problematic because of their infrequent occurrence. Therefore, data on which probability estimates are based are limited. As a result, insurance underwriters often charge higher premiums for ambiguous risks and uncertainty of losses than for wellspecified risks. A study by Kunreuther et al. (1995) shows that underwriters set premiums between 1.43 and 1.77 times higher for highly ambiguous risks and uncertain losses than for nonambiguous risks.²³ In addition, private insurers do not offer policies to cover water damage from hurricanes and do not actively promote earthquake coverage because the potential financial losses from natural catastrophes are so severe (Kunreuther, 1996). Actual coverage for some types of natural disasters is limited, even in countries with highly developed insurance markets. Nevertheless, some countries are better able to reduce the risks associated with natural disasters with insurance. However, data limitations prevent us from incorporating information on crosscountry differences in ability to insure in our empirical analysis.

We note, however, that a substantial percentage of disaster damages are not insured, even in industrialized countries. For example, the earthquake in Kobe, Japan, in January 1995 caused an estimated US\$114 billion in damages, but only 3% of the property in the prefecture where Kobe is located was covered by earthquake insurance (New York Times, 1995). However, an earthquake of this magnitude was unexpected in Kobe. In a widely perceived hazardous area like Tokyo, only 16% of the properties were insured at the time of the Kobe earthquake (Economist, 1997). Horwich (2000) discusses government restrictions that limit property insurance markets in Japan. In the United States, total economic damages from Hurricane Andrew, which swept the Florida coastline south of Miami in August 1992, caused over US\$25 billion in damage, but total private insurance claims were only US\$15.5 billion (Insurance Research Council and Insurance Institute for Property Loss Reduction, 1995).

In many countries, government provides some disaster relief. For example, in the United States the federal government may provide disaster assistance to a state that has experienced a major disaster. Does such aid provide sufficient protection, and do agents believe they will be bailed out by government should they incur a loss? Governmentsponsored disaster relief provides limited assistance, but it does not fully protect individuals from the potential losses they may incur. Further, evidence based on survey data suggests that homeowners in the United States do not expect government relief should they suffer damage from a disaster. In fact, most homeowners expect to rely on their own resources or borrowing to finance their recovery (Kunreuther, 1996). For these reasons, agents bear at least some natural disaster risk.

Hypotheses

The preceding discussion yields several hypotheses that we test empirically. First, the effect of disaster risk on long-run physical capital investment is ambiguous. Disaster risk lowers the expected return to physical capital so that we would expect lower rates of physical capital investment. However, the potential increase in human capital induced by natural disasters may increase the return to physical capital, leading to an increase in physical capital investment. Also, some resources are used for disaster management and physical capital replacement following a disaster so that physical capital investment would increase. Second, because human capital is generally less vulnerable to disasters than physical capital, disaster risk, in the context of endogenous growth theory, could lead to increased human capital investment. The increase in human capital together with the human capital externality could lead to higher rates of economic growth. Finally, if disasters serve as an impetus for adopting new technologies, there could be a direct positive effect on total factor productivity and therefore on economic growth.

^{23.} In the study by Kunreuther et al. (1995), an ambiguous probability refers to the case where "there is wide disagreement about the estimate of p and a high degree of uncertainty among experts." A well-specified loss (L) means that all experts agree that, if a specific event occurs, the loss will equal L. An uncertain loss refers to the situation were the experts' best estimate of a loss is L, with estimates ranging from L_{\min} to L_{\max} .

On the other hand, it may be that risk and losses to physical capital are larger than the human capital gains. Furthermore, if disasters are viewed as a serious threat to life (a risk to human capital), then both physical and human capital investment would be reduced. Also, if human capital is important for the adoption of new technology, growth of total factor productivity might be curtailed, as would economic growth. In the next, section we empirically examine the relationships between disasters, physical and human capital investment, and total factor productivity to ascertain the routes through which disaster risks affect economic growth.

V. DISASTERS, INVESTMENT, AND TOTAL FACTOR PRODUCTIVITY

Our initial analysis shows that natural disasters affect economic growth, but we hypothesize that disasters affect growth through investment decisions and total factor productivity. We now turn our attention directly to the affects of disasters on physical and human capital investment and on growth in total factor productivity.

Physical Capital Accumulation

We begin by estimating the determinants of physical capital investment with disasters included as explanatory variables. We estimate the relationship between the disaster variables and physical capital investment while controlling for initial 1960 per capita GDP and the initial 1960 level of human capital. In Table 6, we report the effects of the disaster variables on three measures of physical capital accumulation used in previous studies.²⁴ We use several measures of physical capital to reduce concerns about obtaining spurious empirical results. These regressions show that the disaster coefficients in the physical capital investment regressions are generally negative but not statistically significant.²⁵ Also, found in Table 6

24. See Appendix A for detailed information and specific definitions for these measures of physical capital accumulation.

are several growth equations that include measures of physical capital accumulation. However, including the physical capital variables in the growth regressions has virtually no effect on the magnitude or significance of the disaster variables. The empirical evidence suggests that natural disasters do not affect economic growth through physical capital accumulation.

Human Capital Accumulation

Table 7 reports the effect of the disaster variables on four measures of human capital accumulation.²⁶ Again, we use several measures of human capital to reduce chances of obtaining spurious results. We estimate the relationship between the disaster variables and each measure of human capital accumulation while controlling for initial per capita GDP and the initial level of human capital. The climatic disaster variables are significant and positively correlated with every measure of human capital accumulation. However, the effects of geologic disasters are negative but generally not statistically significant. Consider the GDP growth regressions also found in Table 7. Note that when measures of human capital are included in the regressions, the magnitude and significance of the climatic disaster variables in several cases are reduced, although they are still statistically significant. From the results presented in Table 7, we infer that climatic disasters lead to a greater emphasis on human capital accumulation, which subsequently induces a higher GDP growth rate. However, it appears that there may be another route through which disasters affect growth because the disaster variables still maintain some statistical significance while controlling for human capital accumulation.

Total Factor Productivity

As previously discussed, disasters may serve as an impetus to adopt new technologies and thus affect factor productivity

^{25.} However, if we control for human capital accumulation in our investment model, we observe a negative relationship between climatic disasters and investment. In estimates of physical capital investment that are not presented, we include human capital accumulation as

a control. This set of regressions shows that once we control for human capital accumulation, climatic disasters have a statistically significant negative effect on physical capital accumulation.

^{26.} See Appendix A for detailed information and specific definitions for these measures of human capital accumulation.

TABLE 6Growth in Physical Capital and Natural Disasters

| Dependent Variable | Log of Initial Income | Log of Initial Schooling | Per Land Climatic_ Davis | Per Land Geologic_ Davis | Per Land Climatic_ CRED | Per Land Geologic_ CRED | No. of Obs. | f Adj. <i>R</i> ² |
|-----------------------------------|-----------------------------|--------------------------------|--------------------------------|--------------------------------|-------------------------------|-------------------------------|----------------|----------------------|
| (1) Investment | 0.0114 (0.9415) | 0.0107 (1.0293) | -0.0047 (-1.3781) | 0.0018 (0.3239) | | | 89 | 0.5695 |
| (2) Investment | 0.0147 (1.1832) | 0.0115 (1.0591) | | | -0.0082 (-2.0027) | 0.0027 (0.4056) | 89 | 0.5751 |
| (3) Capital Growth_KL | -0.2221 (-1.7054) | 0.0039 (0.0687) | -0.0358 (-1.1607) | 0.0015 (0.0421) | | | 89 | 0.3374 |
| (4) Capital Growth_KL | -0.2173 (-1.6616) | -0.0046 (-0.0777) | | | 0.0439 (1.0680) | -0.0924 (-1.3543) | 89 | 0.3364 |
| (5) Capital Growth_BS | -0.0554 (-0.4765) | 0.0419 (0.6387) | -0.0437 (-1.4708) | -0.0018 (-0.0472) | | | 89 | 0.3089 |
| (6) Capital Growth_BS | -0.0331 (-0.2707) | 0.0401 (0.6048) | | | -0.0112 (-0.2661) | -0.0276 (-0.4251) | 89 | 0.2889 |
| Dependent Variab | ole: Per Capi | ta GDP Grow | th (1960–1990 | Average) | | | | |
| | | (7) | (8) | (9) | (10) | (11 |) | (12) |
| Per land climatic_ | Davis | 0.0022 (3.5224) | | 0.0024 (4.0973) | | 0.00 (3.24 | | |
| Per land geologic | | -0.0032 (-2.7725) | | -0.0033 (-3.3442) | | -0.00 (-3.19) | | |
| Per land climatic_ | CRED | | 0.0033 (2.9821) | | 0.0026 (3.0937) |) | | 0.0028 (2.4077) |
| Per land geologic | _CRED | | -0.0011 (-0.9389) | | -0.0009 (-0.7851) | 1 | | -0.0011 (-0.9004) |
| Growth in Capital | I_KL | | | 0.0145 (7.1824) | 0.0136 (6.1887) |) | | |
| Growth in Capital | I_BS | | | | | 0.01 (5.90 | | 0.0157 (5.0853) |
| No. of observation Adjusted R^2 | ns | 89 0.6155 | 89 0.5945 | 89 0.7957 | 89 0.7504 | 89 0.76 | 561 | 89 0.7293 |

Notes: Numbers in parentheses are t values based on the White (1980) heteroskedasticity-consistent covariance matrix. A constant term and regional dummy variables for Sub-Saharan Africa, Latin America, NIES and ASEAN, and OECD are included but not reported here. Other explanatory variables used in Table 4 are included but not reported here.

over time. We use a measure of total factor productivity employed by Coe and Helpman (1995) and Coe et al. (1997), who define total factor productivity as

(3)
$$F = Y/[K^{\beta}L^{1-\beta}],$$

where Y is GDP, K is the total (private plus public) stock of capital, and L is the total labor force. This measure of total factor productivity embodies the institutional setting, political climate, human capital, the state of technology, etc.

In columns 1 and 2 of Table 8, we present regression estimates of the change in total factor productivity that include the disaster variables while controlling for other variables previously found to be important characteristics of total factor productivity growth. The following factors are included as control variables: the natural logarithm of the initial level of 1960 secondary schooling achievement, the average ratio of real domestic investment to real GDP for the 1960–90 period, a measure of the openness of the economy, openness

TABLE 7Growth in Human Capital and Natural Disasters

| Dependent Variable | Log of Initial Income | Log of Initial Schooling | Per Land Climatic Davis | | | c_ Geolog | gic_ No. o | |
|------------------------------------|-----------------------------|--------------------------------|-------------------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| (1) Secondary school enrollment | 0.1077 (3.4874) | 0.0325 (1.4581) | 0.0172 (1.7371) | -0.0320 (-1.9405 | | | 89 | 0.7807 |
| (2) Secondary school enrollment | 0.1002 (3.3273) | 0.0316 (1.4804) | | | 0.0342 | | | 0.7797 |
| (3) Difference in Schooling year | 0.4002 (2.4180) | -0.1631 (-2.0532) | 0.1233 (4.0304) | -0.0918 (-1.3232) | | | 89 | 0.3245 |
| (4) Difference in Schooling year | 0.3356 (2.1035) | -0.1692 (-2.1262) | | | 0.1536 (2.946) | | | 0.2904 |
| (5) Growth in Schooling year | 0.0084 (1.9355) | -0.0263 (-6.2512) | 0.0013 (1.6243) | -0.0017 (-1.4106) | | | 89 | 0.7169 |
| (6) Growth in Schooling year | 0.0074 (1.8447) | -0.0266 (-6.4797) | | | 0.0035 | | | 0.7264 |
| (7) Quality of human capital_HK | 4.5924 (1.8413) | 2.6474 (1.8689) | 1.0720 (1.9791) | -1.5458 (-1.6540 | | | 78 | 0.5648 |
| (8) Quality of human capital_HK | 3.7562 (1.7161) | 2.1523 (1.7548) | | | 3.0675 (4.4373 | | | 0.6258 |
| Dependent Variable: | Per Capita C | GDP Growth | ı (1960–1990 |) Average) | | | | |
| | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) |
| Per land climatic_Davis | 0.0018 (2.5118) | | 0.0016 (2.2603) | | 0.0018 (2.7090) | | 0.0020 (3.3721) | |
| Per land geologic_Davis | -0.0027 (-2.1031) | | -0.0027 (-2.2449) | | -0.0028 (-2.4443) | | -0.0034 (-3.0139) | |
| Per land climatic_CRED | | 0.0024 (2.1349) | | 0.0023 (2.0099) | | 0.0022 (1.8519) | | 0.0022 (2.2706) |
| Per land geologic_CRED | | -0.0002 (-0.1646) | | -0.0007 (-0.6364) | | -0.0004 (-0.3200) | | -0.0009 (-0.8470) |
| Secondary school enrollment | 0.0184 (1.3442) | 0.0237 (1.7958) | | | | | | |
| Difference in schooling year | | | 0.0042 (2.0495) | 0.0048 (2.6991) | | | | |
| Growth in schooling year | | | | | 0.2066 (2.4582) | 0.2067 (2.4829) | | |
| Quality of human capital_HK | | | | | | | 0.0002 (1.2439) | 0.0002 (1.2639) |
| No. of observations Adjusted R^2 | 89 0.6231 | 89 0.6106 | 89 0.6299 | 89 0.6156 | 89 0.6423 | 89 0.6187 | 78 0.6454 | 78 0.6025 |

Notes: Numbers in parentheses are t values based on the White (1980) heteroskedasticity-consistent covariance matrix. A constant term and regional dummy variables for Sub-Saharan Africa, Latin America, NIES and ASEAN, and OECD are included but not reported here. Other explanatory variables used in Table 4 are included but not reported here.

interacted with initial income, and the share of exports of primary products in GNP.

The adjusted R^2 indicates that more than 50% of the variation in the changes in total factor productivity is accounted for in the models. The coefficients on the con-

trol variables show that greater investment and openness, and a smaller share of exports of primary products in GNP lead to increases in the growth of total factor productivity.

Turning to the disaster variables, note that the coefficients on the climatic disaster

TABLE 8
Growth in Total Factor Productivity and Natural Disasters

| | TFP1990 |)/TFP1971 | Per Capita GDP Growth | | |
|---|--------------------|---------------------|-----------------------|---------------------|--|
| Dependent Variable | (1) | (2) | (3) | (4) | |
| Constant | 0.9643 (8.9216) | 0.8970 (6.0498) | 0.0583 (1.9930) | 0.0562 (1.7555) | |
| Log of initial income | | | -0.0088 (-3.0683) | -0.0088 (-2.7713) | |
| Log of secondary schooling | 0.0291 (1.3589) | 0.0165 (0.6047) | 0.0016 (1.2692) | 0.0013 (1.0258) | |
| Fertility | | | -0.0022 (-1.2841) | -0.0025 (-1.5471) | |
| Investment | 1.4356 (2.9180) | 1.6139 (3.5098) | 0.0777 (2.6569) | 0.0775 (2.6794) | |
| Government consumption | | | -0.0552 (-1.8530) | -0.0529 (-2.0024) | |
| Trade | | | 0.0036 (0.9616) | 0.0037 (0.8102) | |
| Openness | 1.3787 (2.2284) | 1.5620 (2.5377) | | | |
| Openness * log of initial income | -0.1323 (-1.6049) | -0.1666 (-2.1005) | | | |
| Share of exports of primary products in GNP | -0.8094 (-2.9922) | -0.9924 (-5.0682) | | | |
| TFP1990/TFP1971 | | | 0.0262 (3.9721) | 0.0281 (4.4776) | |
| Per land climatic_Davis | 0.0402 (2.9313) | | 0.0013 (1.7242) | | |
| Per land geologic_Davis | -0.0131 (-0.5857) | | -0.0015 (-1.4137) | | |
| Per land climatic_CRED | | 0.0901 (2.3412) | | 0.0003 (0.1870) | |
| Per land geologic_CRED | | -0.0750 (-1.5666) | | 0.0022 (1.0896) | |
| No. of observations Adjusted R^2 | 71 0.5322 | 71 0.5845 | 75 0.7136 | 75 0.7129 | |

Notes: Numbers in parentheses are t values based on the White (1980) heteroskedasticity-consistent covariance matrix. In regression (1) and (2), regional dummy variables for Sub-Saharan Africa, Latin America, NIES and ASEAN, and OECD are included but not reported here.

variables are positive and statistically significant, whereas the coefficients on the geologic disaster variables are negative but statistically insignificant. In columns (3) and (4), we also present the per capita GDP growth estimates. In these estimates, a variable that measures increases in total factor productivity is included in the regressions. Here the coefficients on the disaster variables decrease substantially and generally become statistically insignificant by conventional standards.

Table 8 contains compelling empirical evidence that climatic disasters are associated with growth in factor productivity. From these results, we infer that disasters provide opportunities to update the capital stock and adopt new technologies. We also suggest that disaster risks necessitate adaptability, so that cultures experiencing disasters may be able to adopt new technologies more readily. Factor productivity appears to be the primary route through which disasters affect growth.

VI. CONCLUSIONS

In this article, we use cross-country data to examine the long-run relationships among disaster risk, investment decisions, total factor productivity, and economic growth. Although our theoretical discussion suggests that the effects of disasters on the economy are generally ambiguous, the empirical analysis shows that while controlling for many factors, climatic disasters are positively correlated with economic growth, human capital investment, and growth in total factor productivity, whereas geologic disasters are negatively correlated with growth. Our results show that total factor productivity appears to be the primary route through which disasters affect growth. Thus, natural disasters play an important role in macroeconomic activity, but not necessarily in ways that one might expect.

Though the disaster variables are somewhat crude measures and do not warrant reliance on specific parameter estimates, we think it is useful to provide some indication of the magnitudes of the effects. Using the growth regression in column five of Table 4, the coefficient on disasters normalized by land area indicates that a one-standarddeviation increase in climatic disasters results in a 22.4% increase in the average annual rate of economic growth. That is, one standard deviation in measured climatic disasters increases the average annual rate of economic growth by about 0.47. The alternate climatic disaster variables yield effects of similar magnitudes. Although our theoretical discussion does not provide guidance regarding the size of the coefficients on the disaster variables, from an empirical perspective the estimated effects are not unreasonably high nor inconsequential.

Despite the crudeness of our disaster data we are able to obtain statistically meaningful results. Future research aimed at identifying more accurate data on disaster risk, and in particular, detailed information on the probabilities of capital destruction and death would be a valuable contribution. Similarly, some countries may have highly developed insurance markets and therefore may be able to reduce the risks associated with disasters. Our study takes no account of the differential ability to insure against hazards.

Mankiw et al. (1992) indicate that future research effort in the area of economic growth should be directed at explaining why physical and human capital accumulation vary so much from country to country. They highlight differences in tax policies, tastes for children, and political stability as possible determinants of these cross-country differences. More recently, Temple (1999) suggests that our understanding of factor accumulation is still weak. Our article presents new evidence on the determinants of factor accumulation and factor productivity not yet identified in the literature. The evidence reported herein supports the notion that the prevalence of disasters is an important factor for individual decision processes, and that the sum of these individual responses has significant long-run macroeconomic implications.

APPENDIX TABLE A1Definitions and Sources of Variables

| Variables | Definition | Source |
|---|--|---------------|
| Per capita GDP growth | Average annual growth rate of real per capita GDP for the period 1960-90 | SH |
| Log of initial income Log of secondary schooling | Logarithm of real per capita GDP in 1960 Logarithm of secondary schooling years in the total population aged 15 and over in 1960 | SH BL2 |
| Fertility Investment | Average net fertility rate for the period 1960–85 Average ratio of real domestic investment to real GDP for the period | BL1 BL1 |
| Government consumption | 1960–90 Average ratio of government consumption to real GDP for the period 1960–90 | BL1 |
| Trade Total disaster_Davis | Average ratio of export + import to real GDP for the period 1960–90 Logarithm of 1 + number of total disaster events (landslide, earth-quake, volcano, flood, cyclone, hurricane, typhoon, tornado, and storm) | SH Davis |
| Total disaster_CRED Per land disaster_Davis | Logarithm of $1+$ number of total disaster events Logarithm of $1+$ number of total disaster events per million | CRED Davis |
| Per land disaster_CRED | square km Logarithm of 1 + number of total disaster events per million square km | CRED |
| Total climatic_Davis | Logarithm of 1 + number of climatic disaster events (flood, cyclone, hurricane, typhoon, tornado, and storm) | Davis |
| Per land climatic_Davis | Logarithm of 1 + number of climatic disaster events per million square km | Davis |
| Total geologic_Davis | Logarithm of 1+number of geologic disaster events (landslide, earthquake, and volcano) | Davis |
| Per land geologic_Davis | Logarithm of 1+number of geologic disaster events per million square km | Davis |
| Total climatic_CRED Per land climatic_CRED | Logarithm of 1+number of climatic disaster events Logarithm of 1+number of climatic disaster events per million square km | CRED CRED |
| Total geologic_CRED Per land geologic_CRED | Logarithm of 1+number of geological disaster events Logarithm of 1+number of geological disaster events per million square km | CRED CRED |
| Log of land area | Logarithm of land area (square km) | WDI |
| Log of population | Logarithm of total population in 1960 | WDI |
| Log of urbanization | Logarithm of the ratio of urban population to total population in 1960 | WDI |
| Latitude Tropics | Absolute latitude Dummy for tropical countries if absolute value of latitude is less than or equal to 23. | GDN GDN |
| Sub-Saharan Africa Latin America NIES and ASEAN | Dummy for Sub-Saharan African countries Dummy for Latin-American Countries Dummy for NIES and ASEAN members | |
| OECD Growth in Capital_KL | Dummy for OECD members Average annual growth rate of physical capital stock per capita constructed by King and Levine (1994) for the period 1960–85 | KL |
| Growth in Capital_BS | Average annual growth rate of physical capital stock per capita constructed by Benhabib and Spiegel (1994) for the period 1965–85 | BS |
| Secondary school enrollment | Average gross secondary enrollment ratio for the period 1960–85 | WDI |
| Difference in schooling year | Difference between secondary schooling year in 1990 and secondary schooling year in 1960 | BL2 |
| Growth in schooling year | Average annual growth rate of secondary schooling year for the period 1960–90 | BL2 |

continued

APPENDIX TABLE A1 continued

| Variables | Definition | Source |
|--|--|---------------------|
| Quality of human capital_HK TFP1990/TFP1971 Openness | Measure of schooling quality based on student cognitive performance in science and mathematics Ratio of TFP in 1990 to TFP in 1971 The fraction of years during the period 1965–90 in which the country is rated as an open economy according to the criteria in Sachs and Warner (1995) | HK CH, CHH SW |
| Openness * log of initial income Share of exports of primary products in GNP | Openness * logarithm of real per capita GDP in 1960 Share of exports of primary products in GNP in 1970 | SW |

Sources: BL1: Barro and Lee (1994). BL2: Barro and Lee (1996).

BS: Benhabib and Spiegel (1994). CCH: Coe et al. (1997).

CH: Coe and Helpman (1995). CRED: EMDAT. (2000).

Davis: Davis (1992). GDN: Easterly and Sewadeh (2002).

HK: Hanushek and Kim (1995).

KL: King and Levine (1994). SH: Summers and Heston (1994).

SW: Sachs and Warner (1997). WDI: World Development Indicators (1998).

APPENDIX TABLE B1 List of Countries

| Algeria | Haiti (1) | Pakistan (1) |
|--------------------------|---------------------------|----------------------|
| Argentina | Honduras | Panama (3) |
| Australia | Hong Kong, China | Papua New Guinea (3) |
| Austria | Iceland (2, 3) | Paraguay |
| Bangladesh (1) | India | Peru |
| Barbados (2, 3) | Indonesia | Philippines |
| Belgium | Iran, Islamic Rep. (2, 3) | Portugal |
| Bolivia | Iraq (2, 3) | Senegal (1) |
| Botswana (2, 3) | Ireland | Singapore |
| Brazil | Israel | South Africa (2, 3) |
| Cameroon | Italy | Spain |
| Canada | Jamaica (2, 3) | Sri Lanka |
| Central African Republic | Japan | Swaziland (2, 3) |
| Chile | Jordan | Sweden |
| Colombia | Kenya | Switzerland |
| Congo, Dem. Rep. | Korea, Rep. | Syrian Arab Republic |
| Costa Rica | Lesotho $(2,3)$ | Thailand |
| Cyprus (2, 3) | Liberia $(1,2,3)$ | Togo |
| Denmark | Malawi (1) | Trinidad and Tobago |
| Dominican Republic | Malaysia | Tunisia (2, 3) |
| Ecuador | Mali (1) | Turkey |
| El Salvador | Mauritius | Uganda (1) |
| Fiji (3) | Mexico | United Kingdom |
| Finland | Mozambique $(2,3)$ | United States |
| France | Nepal (1, 3) | Uruguay |
| Germany | Netherlands | Venezuela |
| Ghana | New Zealand | Zambia |
| Greece | Nicaragua (2, 3) | Zimbabwe |
| Guatemala (3) | Niger (1) | Taiwan |
| Guyana | Norway | |

Notes: The number in parentheses represents the data availability: (1) not available in the sample of 78 countries, (2) not available in the sample of 75 countries, and (3) not available in the sample of 71 countries, respectively. See Appendix Table A1 for a listing of data sources and Appendix Table C1 for the number of countries for which data are available.

APPENDIX TABLE C1
Summary of Statistics of all Variables Used in the Analysis

| | Mean | Standard Deviations | No. of Observations |
|---|--------|------------------------|------------------------|
| Per capita GDP growth | 0.021 | 0.018 | 89 |
| Log of initial income | 7.514 | 0.859 | 89 |
| Log of secondary schooling | -0.954 | 1.375 | 89 |
| Fertility | 4.346 | 1.509 | 89 |
| Investment | 0.194 | 0.081 | 89 |
| Government consumption | 0.161 | 0.064 | 89 |
| Trade | 0.618 | 0.403 | 89 |
| Total disaster Davis | 0.894 | 1.014 | 89 |
| Total disaster CRED | 0.567 | 0.540 | 89 |
| Per land disaster Davis | 1.680 | 2.026 | 89 |
| Per land disaster CRED | 1.496 | 1.430 | 89 |
| Total climatic Davis | 0.673 | 0.910 | 89 |
| Per land climatic Davis | 1.408 | 1.988 | 89 |
| Total geologic_Davis | 0.428 | 0.723 | 89 |
| Per land geologic Davis | 0.645 | 1.196 | 89 |
| Total climatic CRED | 0.450 | 0.482 | 89 |
| Per land climatic CRED | 1.306 | 1.426 | 89 |
| Total geologic CRED | 0.204 | 0.279 | 89 |
| Per land geologic_CRED | 0.584 | 0.818 | 89 |
| Log of land area | 12.16 | 1.991 | 89 |
| Log of population | 8.661 | 1.522 | 89 |
| Log of urbanization | 3.375 | 0.932 | 89 |
| Latitude | 25.40 | 16.63 | 89 |
| Tropics | 0.506 | 0.503 | 89 |
| Sub-Saharan Africa | 0.225 | 0.420 | 89 |
| Latin America | 0.258 | 0.440 | 89 |
| NIES and ASEAN | 0.079 | 0.271 | 89 |
| OECD | 0.258 | 0.440 | 89 |
| Growth in capital KL | 0.668 | 0.567 | 89 |
| Growth in capital_BS | 0.424 | 0.532 | 89 |
| Secondary school enrollment | 0.399 | 0.254 | 89 |
| Difference in schooling year | 0.987 | 0.745 | 89 |
| Growth in schooling year | 0.041 | 0.031 | 89 |
| Quality of human capital_HK | 44.94 | 12.90 | 78 |
| TFP1990/TFP1971 | 1.163 | 0.289 | 71 |
| | 1.148 | 0.288 | 75 |
| Openness | 0.469 | 0.456 | 71 |
| Openness * log of initial income | 3.771 | 3.768 | 71 |
| Share of exports of primary products in GNP | 0.117 | 0.103 | 71 |

REFERENCES

- Albala-Bertrand, J. *Political Economy of Large Natural Disasters*. Oxford: Clarendon Press, 1993.
- Alexander, D. *Natural Disasters*. New York: Chapman and Hall, 1993.
- Azariadis, C., and A. Drazen. "Threshold Externalities in Economic Development." *Quarterly Journal of Economics*, 105, 1990, 501–26.
- Barro, R. "Economic Growth in a Cross Section of Countries." *Quarterly Journal of Economics*, 106, 1991, 407–43.
- Barro, R., and J. Lee. "Data Set for a Panel of 138 Countries." Taken from the NBER Web page, 1994. Available at www.nber.org/ftp/barro.lee/.
- —. "International Measures of Schooling Years and Schooling Quality." *American Economic Review*, 86, 1996, 218–23.
- Benhabib, J., and M. Spiegel. "The Role of Human Capital in Economic Development: Evidence from Aggregate Cross-Country Data." *Journal of Monetary Economics*, 34, 1994, 143–73.
- Brookshire, D., M. Thayer, J. Tschirhart, and W. Schulze. "A Test of the Expected Utility Model: Evidence from Earthquake Risks." *Journal of Political Economy*, 93, 1985, 369–89.
- Coe, D., and E. Helpman. "International R&D Spillovers." *European Economic Review*, 39, 1995, 859–87
- Coe, D., E. Helpman, and A. Hoffmaister. "North-South R&D Spillovers." *Economic Journal*, 107, 1997, 134–49.
- Dacy, D. C., and H. C. Kunreuther. The Economics of Natural Disasters. New York: Free Press, 1969.
- Davis, L. Natural Disasters: From the Black Plague to the Eruption of Mt. Pinatubo. New York: Facts on File, 1992.
- Dréze, J., and F. Modigliani. "Consumption Decisions under Uncertainty." *Journal of Economic Theory*, 5, 1972, 308–35.
- Dynan, K. "How Prudent Are Consumers?" *Journal of Political Economy*, 101, 1993, 1104–13.
- Easterly, W., and M. Sewadeh. "Global Development Network Growth Database." Taken from the World Bank Research Departments Web page. 2002. Available at www.worldbank.org/research/growth/GDNdata.htm.
- Economist. "A Survey of Japanese Finance." 28 June 1997.
- EMDAT. The OFDA/CRED International Disaster Database. Universite Catholicque de Louvain, Brussels, Belgium. Available online at www.md. ucl.ac.be/cred. 2000.
- Guiso, L., T. Jappelli, and D. Terlizzese. "Earnings Uncertainty and Precautionary Saving." *Journal of Monetary Economics*, 30, 1992, 307–37.
- Hakansson, N. H. "Optimal Investment and Consumption Strategies under Risk for a Class of Utility Functions." *Econometrica*, 38, 1970, 587–607.
- Hall, R., and C. Jones. "The Productivity of Nations." NBER Working Paper No. 5812, 1996.
- Hanushek, E., and D. Kim. "Schooling, Labor Force Quality, and Economic Growth." NBER Working Paper No. 5399, 1995.

- Horwich, G. "Economic Lessons from the Kobe Earthquake." *Economic Development and Cultural Change*, 48, 2000, 521–42.
- Insurance Research Council and Insurance Institute for Property Loss Reduction. *Coastal Exposure and Community Protection: Andrew's Legacy*. Wheaton, IL: IRC, 1995.
- Jones, E. L. The European Miracle: Environments, Economies and Geopolitics in the History of Europe and Asia. Cambridge: Cambridge University Press, 1981.
- Kimball, M. "Precautionary Saving in the Small and in the Large." *Econometrica*, 58, 1990, 53–73.
- King, R., and R. Levine. "Capital Fundamentalism, Economic Development, and Economic Growth." Carnegie-Rochester Conference Series on Public Policy, 40, 1994, 259–92.
- Kunreuther, H. "Mitigating Disaster Losses through Insurance." Journal of Risk and Uncertainty, 12, 1996, 171–87.
- Kunreuther, H., J. Meszaros, R. Hogarth, and M. Spranca. "Ambiguity and Underwriter Decision Processes." *Journal of Economic Behavior and Organization*, 26, 1995, 337–53.
- Leland, H. "Saving and Uncertainty: The Precautionary Demand for Saving." *Quarterly Journal of Economics*, 82, 1968, 465–72.
- Levine, R., and D. Renelt. "A Sensitivity Analysis of Cross-Country Growth Regressions." *American Economic Review*, 82, 1992, 942–63.
- Lucas, R. "On the Mechanics of Economic Development." *Journal of Monetary Economics*, 22, 1988, 3–42.
- Mankiw, G., D. Romer, and D. Weil. "A Contribution to the Empirics of Economic Growth." *Quarterly Journal of Economics*, 106, 1992, 407–37.
- Merton, R. C. "Lifetime Portfolio Selection under Uncertainty: The Continuous Time Case." *Review of Economics and Statistics*, 51, 1969, 247–57.
- New York Times. "Quake in Japan: The Response." 19 January 1995, A11.
- Otero, R. and R. Marti. "The Impacts of Natural Disasters on National Economies and the Implications for the International Development and Disaster Community," in *Disaster Prevention for Sustainable Development: Economic and Policy Issues*, edited by M. Munasinghe and C. Clarke. Geneva and New York: International Decade for Natural Disaster Reduction and World Bank, 1995, 11–40.
- Ram, R. "Tropics and Economic Development: An Empirical Investigation." World Development, 25, 1997, 1443–52.
- Sachs, J., and A. Warner. "Fundamental Sources of Long-Run Growth." *American Economic Review Papers and Proceedings*, 87, 1997, 184–88.
- Sandmo, A. "Capital Risk, Consumption and Portfolio Choice." *Econometrica*, 37, 1969, 586–99.
- Shah, B. V. "Is the Environment Becoming More Hazardous? A Global Survey 1947 to 1980." *Disasters*, 7, 1983, 202–9.
- Shaw, H. "Major Tokyo Quake World Cost 1.2 Trillion, Study Says." As quoted in the *New York Times*, 20 September 1994, C9.

- Skidmore, M. "Risk, Natural Disasters, and Household Savings in a Life Cycle Model." *Japan and the World Economy*, 13, 2001, 15–34.
- Skinner, J. "Risky Income, Life-Cycle Consumption and Precautionary Savings." *Journal of Monetary Economics*, 22, 1988, 237–55.
- Summers, R., and A. Heston. "The Penn World Table (Mark 5.6)." 1994. Available at http: pwt.econ.upenn.edu/.
- Temple, J. "The New Growth Evidence." *Journal of Economic Literature*, 37, 1999, 112–56.
- Tol, R., and F. Leek. "Economic Analysis of Natural Disasters," in *Climate, Change and Risk*, edited

- by T. E. Downing, A. J. Olsthoorn, and R. S. J. Tol. London: Routledge, 1999.
- Toya, H., and M. Skidmore. "Economic Development and the Effects of Natural Disasters." Working Paper, Nagoya City University, 2000.
- WDI. World Development Indicators on CD-ROM. The World Bank, 1998.
- White, H. "A Heteroskedasticity-Consistent Covariance Matrix and a Direct Test for Heteroskasticity." *Econometrica*, 48, 1980, 721–46.
- Zeldes, S. "Optimal Consumption with Stochastic Income: Deviations from Certainty Equivalence." Quarterly Journal of Economics, 104, 1989, 275–98.