Climate and Development

William A. Masters*	and	Jeffrey D. Sachs
Associate Professor,		Director,
Department of Agricultural Economics		Center for International Development
Purdue University		Harvard University

-- Draft for comments only –
Paper presented at the annual meetings of the AEA, New Orleans LA, 7 January 2001

Abstract: We test for links between physical geography and economic development using a system of simultaneous equations, identifying specific growth mechanisms through which geographic variables might affect income. We find the most important channels to be the health effects of malaria prevalence, the agricultural effects of seasonal frost, and the urbanization effects of coastal location. Through these channels, the differences between today's high-income countries and the rest of the world in malaria prevalence, seasonal frost and coastal location are associated with 74%, 16% and 15% lower income levels, respectively. Identifying the channels through which geography matters can help policymakers circumvent its effects: our results suggest that R&D for new technologies in health and agriculture to overcome the effects of geography are particularly important in unlocking the growth potential of climatically-disadvantaged regions.

JEL Classification Code: O41, O13

Keywords: Economic growth, geography, simultaneous equations.

* **Corresponding author**:

Department of Agricultural Economics	phone 765 494 4235
Purdue University	fax 765 494 9176
West Lafayette, IN 47907-1145	wmasters@purdue.edu

Climate and Development

Introduction

This paper builds on the recent empirical growth literature, using panel data to test alternative channels through which physical geography might influence the process of economic development.

We follow Hall and Jones (1999) in focusing on long-run processes that influence income levels, and introduce a system of simultaneous equations by which specific endogenous socioeconomic variables may be linked to specific exogenous biophysical factors. Multiple observations for each country, taken at five-year intervals from 1960 through 1993, are used to estimate the magnitude and significance of each relationship.[1]

Growth-accounting studies following Solow (1956, 1957) decompose economic growth into factor accumulation and residual productivity change. Increasingly careful measurement can alter the share attributed to factors, particularly human capital (e.g. Mankiw, Romer and Weil, 1992; Young 1995) -- but this leaves open the question of why those factors accumulate faster in some locations than in others.

Hall and Jones (1999) posit that investment in both physical and human capital may be simultaneously caused by something they call "social infrastructure", which rewards and sustains economic activity. They measure social infrastructure with an index of government policies, and use instrumental variables to identify its effect on the level of output -- but they leave open the question of how particular variables might influence social infrastructure.

A number of recent papers aim to explain policy choice and economic growth in terms of physical geography. Engermann and Sokoloff (1997) argue that agricultural conditions influenced the relative importance of slavery across regions in the 18th and 19th centuries, producing differences in political inequality that affect policies and hence growth. Acemoglu, Johnson and Robinson (2000) argue that disease ecology influenced the migration of Europeans across regions in the 19th century, producing differences in colonial institutions affecting growth.

Climate effects could have a historical role, and also an impact on current resource productivity and policy choices. Bloom and Sachs (1998) and Gallup, Sachs and Mellinger (1999) find considerable evidence for such effects; Masters and Wiebe (2000) provide details in the agricultural sector, while Gallup and Sachs (2000) and McCarthy,

[1] Convergence and dynamics are not modeled here; when estimating the full system we treat all observations for each country as independent draws around the worldwide trend captured by a time dummy. Sequence is considered only in some single-equation equation robustness tests, where AR(1) autocorrelation is allowed.

Wolf and Wu (2000) provide details on the persistent effects of holoendemic malaria in particular.[2]

If geography affects growth only through social history, then the key to faster growth would be faster diffusion of policies and institutions from economically-successful regions. But if geography affects current productivity levels and policy outcomes, then location-specific innovations may be needed. For example, McMillan (2000) posits and tests a model in which the cost structure of agriculture influences policymakers' choices, helping to explain why some African countries have consistently imposed confiscatory taxes on some crops, and pointing to the technological and institutional innovations that would be needed to sustain a low-tax regime.

At a global level, if growth in certain regions is constrained by biophysical conditions affecting agriculture or disease, then public investment in agricultural R&D or public health could help accelerate growth, by changing technological possibilities in those sectors. Without such investment, imitating the economic policies or social institutions of more successful regions would not yield the same result. And if geography's effects are severe enough, even the best-intentioned and best-informed local policymaker might not be able to undertake public investments of the required magnitude -- suggesting a need for outside assistance to overcome local poverty traps.

In this paper we posit and test a number of different channels through which physical geography might affect long-run national income. Each channel is represented by one or more endogenous variables in a system of simultaneous equations, into which measures of climate, disease ecology and physical location also enter.

One channel by which geography might matter is through agricultural output per capita. In the dual-sector growth models of Ranis and Fei (1961), Jorgenson (1961), and then Matsuyama (1992), geographic influences on per-capita output could accelerate or slow growth, by influencing the economy's sectoral composition.

A second kind of mechanism involves human capital, through which better health and education permit sustained growth by means of dynamic externalities or nonrivalries in knowledge. Mankiw, Romer and Weil (1992) among others helped focus attention on this dimension in the empirical-growth literature -- and Gallup, Sachs and Mellinger (1999) raise the question of how disease ecology might influence growth through health and education levels.

A third kind of growth mechanism would involve specialization and learning facilitated by agglomeration, which reduces transaction costs and raises the returns to economic activity, attracting investment and inducing innovation. This mechanism, as posited by Adam Smith (1776), formalized by Murphy, Shleifer and Vishny (1989a, 1989b) and documented empirically by Ades and Glaeser (1999), implies that geography might matter by

[2] A holoendemic disease is one that infects virtually everyone. In certain climate zones, malaria is persistently holoendemic despite substantial eradication efforts, due to very high rates of transmission.

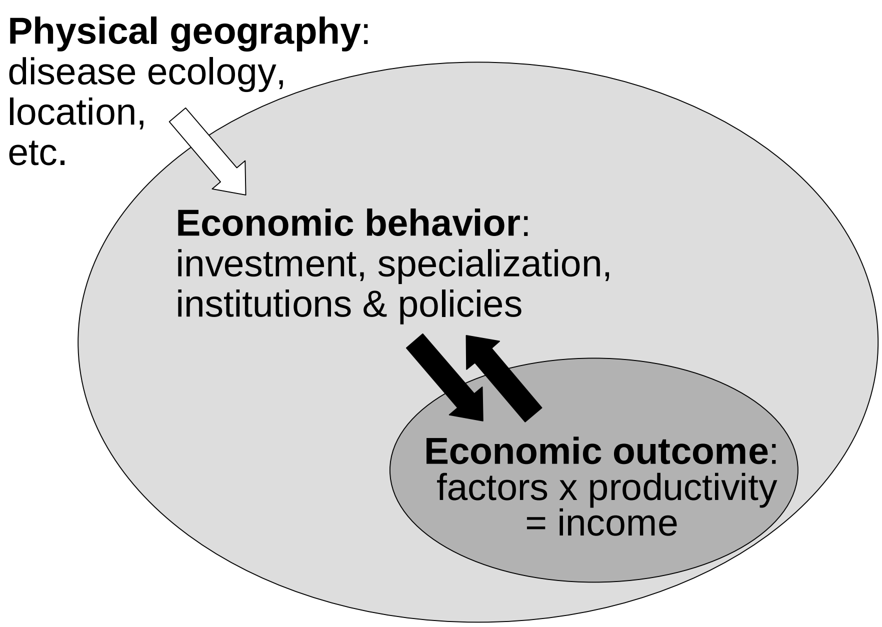
facilitating urbanization, perhaps through larger and faster-growing food surpluses as well as coastal locations.

A fourth kind of growth involves the distinct effect of social institutions on incentives and innovation, following Douglass North and others. Here, the key determinant of growth would be the ability of government institutions to align private and social interests, as measured through an index of institutional quality (e.g. Knack and Keefer 1995).

Methodology

To identify and test the role of climate and other features of physical geography on various growth mechanisms, we use a system-of-equations approach. Figure 1 illustrates the basic idea: we ask whether particular geographic variables can be linked to particular economic choices, and through them to the level of per-capita income, when accounting for reverse causality from income to behavior. A variety of robustness tests follow the presentation and testing of the core model.

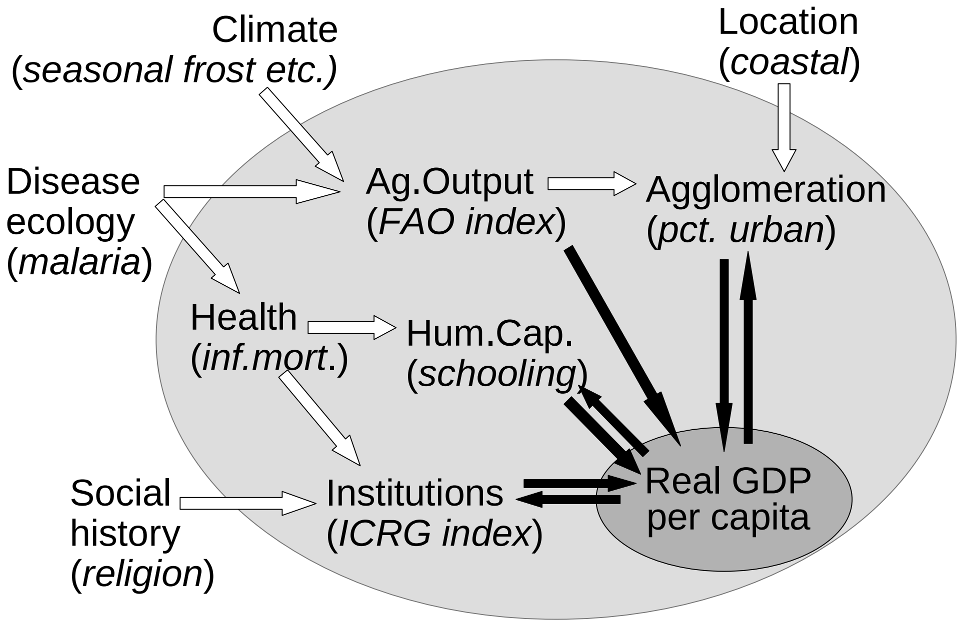
Figure 1. Hypothesized links from geography to per-capita income



Note: Variables outside the shaded region are exogenous and do not change over time.

Our empirical specification of Figure 1 uses four kinds of geographic variables to identify and test the four kinds of growth channels. The specific variables and channels we test are illustrated in Figure 2.

Figure 2. Variables and specification of the simultaneous-equations model



The particular exogenous variables, and their channels of influence on income, are:

(1) climate, measured by the prevalence of seasonal frosts along with other variables, as a determinant of agricultural output per capita, which might affect income directly or through agricultural surpluses that facilitate agglomeration and urbanization;
(2) disease ecology, measured by the prevalence of holoendemic malaria (in 1966), as a determinant of infant mortality which in turn might influence both schooling and institutions;
(3) location, measured by the proportion of a country's land that is within 100 km of a seacoast or navigable river, as a determinant of transport costs to large markets and hence facility of agglomeration for specialization and trade; and
(4) social history, measured by the proportion of a country's population professing particular religions that have spread across the world, as a marker of influence on social institutions.

The exogenous variables we use have all been identified in previous studies as important geographic factors in economic growth. The role of climate, and particularly the influence of winter frost as "the great executioner of nature" (Kamarck 1976) helping to reduce pest and disease pressure, is documented as a factor in economic growth by Masters and McMillan (2000) and on agricultural output by Masters and Wiebe (2000). The role of disease ecology, and the particular importance of holoendemic malaria, is documented by Gallup and Sachs (2000). The role of coastal location, that was stressed by Adam Smith

(1776/1976), is detailed in Mellinger, Sachs, and Gallup (1999). And the role of religion as a factor in social institutions, as stressed by Max Weber (1915/1992) has been found to be a robust correlate of growth in many contexts, most recently by Doppelhofer, Miller and Sala-I-Martin (2000).

Our contribution in this study is to ask whether each of these exogenous factors can be linked to particular endogenous variables associated with economic development, in a way that would help identify the channel through which each factor might operate. These links, as represented in Figure 2, are tested in the following estimating equations. Each estimating equation includes period dummies which capture any secular trends in worldwide technology or market conditions.

The first equation is aimed at capturing the potential influence of climate on agricultural conditions, controlling for other factors:

$$(1) \qquad agoutput_{it} = \alpha_1 + \beta_{11}(agland_{it}) + \beta_{12}(landqual_i) + \beta_{13}(frost_i) + \beta_{14}(rainfall_i) + \beta_{15}(malaria_i) + \delta_{1t} + \varepsilon_{1it}$$

Equation (1) posits agricultural production per capita to be a function of land area per capita, the soil quality of that land, the prevalence of seasonal frost (an overall measure of climate related to agricultural productivity) and total rainfall, plus the initial prevalence of high-level malaria, and dummy variables to capture unobserved changes between time periods.

The next two equations are aimed at testing for human-capital effects:

$$(2) \qquad imrate_{it} = \alpha_2 + \beta_{21}(income_{it}) + \beta_{22}(malaria_i) + \delta_{2t} + \varepsilon_{2it}$$

$$(3) \qquad schooling_{it} = \alpha_3 + \beta_{31}(income_{it}) + \beta_{32}(imrate_{it}) + \delta_{3t} + \varepsilon_{3it}$$

Equation (2) posits the infant-mortality rate (a key indicator of health status) to be driven by economywide income and malaria disease ecology. Equation (3) has average years of schooling (as an indicator of the economy's stock of human capital) driven by economywide income plus the infant mortality rate (which among other things consumes family resources in additional children, at a direct cost to the resources available per child).

The next equation endogenizes institutional arrangements:

$$(4) \qquad institqual_{it} = \alpha_4 + \beta_{41}(income_{it}) + \beta_{42}(imrate_{it}) + \beta_{43}(pctcath_i) + \beta_{44}(pctprot_i) + \beta_{45}(pctmus_i) + \delta_{4t} + \varepsilon_{4it}$$

Equation (4) posits that an index of the quality of government institutions is related to economywide income, the infant mortality rate (as a measure of health), and social history as captured by the percentage of the population that is Protestant, Catholic or Muslim (as measures of long-run social influence from Northern Europe, Southern Europe, or the Middle East respectively).

Finally, the last kind of growth mechanism involves urbanization, and the possible scale effects arising from a greater extent of the market:

$$(5) \qquad urbanization_{it} = \alpha_5 + \beta_{51}(income_{it}) + \beta_{52}(agoutput_{it}) + \beta_{53}(coastal_i) + \delta_{5t} + \varepsilon_{5it}$$

Equation (5) posits the urbanization rate to be a function of income, agricultural output per capita (releasing “surplus” food and labor for off-farm tasks) and access to coasts or navigable rivers (which, by facilitating international trade, could substitute for local food production as well as stimulate agglomeration).

Each of these endogenous variables is then brought together in a levels-accounting framework:

$$(6) \qquad income_{it} = \alpha_6 + \beta_{61}(agoutput_{it}) + \beta_{62}(imrate_{it}) + \beta_{63}(schooling_{it}) + \beta_{64}(instqual_{it}) + \beta_{65}(urbanization_{it}) + \delta_{6t} + \varepsilon_{6it}$$

Variable definitions and data sources

To implement the model we combine the datasets constructed for Bloom and Sachs (1998) and Gallup, Sachs and Mellinger (1999), with those of Masters and McMillan (2000) and Masters and Wiebe (2000), plus Barro and Lee (2000).

For all time-variant data, we use observations at five-year intervals, around 1960, 1965, 1970, 1975, 1980, 1985 and 1990. In most cases these are an average of five annual observations centered around the year indicated (that is, 1963-67 for 1965, 1968-73 for 1970, and so forth), although only three years are available to represent 1960 (that is, 1960-62). For the Barro-Lee data on schooling and also the UN data on infant mortality, single-year observations are used at the corresponding five-year intervals.

The agriculture data, drawn from Masters and Wiebe (2000), originate in FAO (1999) for the index of agricultural output (expressed in real international dollars) and land used in agriculture (expressed in thousands of hectares). The land quality index is constructed by Wiebe et al. (2000) and represents the percentage of a country’s “cropland” and “cropland plus natural mosaic” (classes 12 and 14 in the International Geosphere-Biosphere Programme classification, as reported in USGS 1999) that is reported to be in the top three categories of suitability for agriculture in the World Soil Resources classification scheme (as reported in NRCS 1999).

Climatic data were compiled by Masters and Wiebe (2000) from data published by the International Panel on Climate Change (1999). Frost prevalence refers to the proportion of a country’s land receiving five or more frost days in that country’s winter, defined as December through February in the Northern hemisphere and June through August in the Southern hemisphere. The raw data for this computation were the IPCC’s estimated average number of frost-days per month over the 1961-90 period, across 0.5-degree cells for all land mass except Antartica, interpolated from station observations. (For stations not reporting frost observations, values are estimated from observed temperature level, temperature variation, and precipitation; Frost-days are defined as those where the estimated temperature of ground-level grasses falls below 0 degrees centigrade.) Rainfall is defined as the average total annual precipitation for each cell, averaged over the country's land mass.

Economic data are drawn from the Penn World Tables 5.6 for national income (real GDP per capita, chain indexed), and from the World Bank *World Development Indicators 2000* for urbanization (percentage of the population in urban areas). Data on schooling are drawn from Barro and Lee (2000), from which we use the average number of years of total schooling in the population over age 15. Data on infant mortality rates are drawn from UN (1996), and our data on long-run social history are the percentage of the population estimated to be Protestant, the percentage Catholic, and the percentage Muslim [**citation?**].

For disease ecology, we use the proportion of the country with high-level malaria in 1966, digitized from maps published in WHO (1967). And for the quality of national institutions we use the ICRG index as computed by Knack and Keefer (1995), from data supplied by International Country Risk Services (ICRG).

Regression results

Table 1 shows results from simultaneous estimation of equations (1) through (6). The columns correspond to the equation numbers, and the rows are organized so that the first six show the endogenous variables, in the same order, and the remaining rows show the exogenous variables.

The agriculture equation (column 1) shows a strong direct role for seasonal frost (but not for total precipitation), and also for malarial ecology. The infant-mortality equation (column 2) shows a strong direct role for malarial ecology, as well as for income. The equation for schooling (column 3), in turn, shows a strong effect from infant mortality, as well as an income effect. Similar but smaller effects apply to institutional quality (equation 4), which is also affected by social history (a larger proportion of Protestants is associated with higher institutional quality, Catholics with lower, and Muslims with no effect, relative to the rest of the world population). Finally, the urbanization equation (column 5) shows a very strong effect from agricultural output per person, and also from coastal location, but no residual income effect.

The income equation (column 6), perhaps surprisingly, shows strong effects only for institutional quality, urbanization and schooling. This result is consistent with previous work identifying these channels as important for growth, but in the system-of-equations context we can see how these socioeconomic factors are influenced by other endogenous variables (particularly agricultural output per capita and the infant-mortality rate, which affect urbanization and schooling respectively), as well as exogenous geographic factors.

Looking across all equations, the dummy variables for time after 1960 (which is the omitted period) indicate quite substantial positive trends in agricultural output and urbanization, as well as substantial improvement in infant mortality, but a trend worsening of the institutional quality index when controlling for the improvements in infant mortality and real income. There is no remaining time trend in schooling or income, when controlling for the variables in the model.

Table 2 presents the reduced-form parameters computed from the coefficients of Table 1. The magnitude of effect for malaria prevalence is strikingly high. To see these magnitudes in the context of actual variation in physical geography across countries, Table 2a presents the average values of the exogenous variables for the sub-sample of high-income countries, and for all others in the estimation sample, and the reduced-form impact on income of the difference between them.

The difference in physical geography between high-income countries and the rest of the world is itself striking. As shown in Table 2a, the high-income countries have roughly half as much agricultural land per capita as other countries (0.6 versus 1.2 hectares/person), but over twice as much of that land is in the highest soil-quality categories (23 versus 9 percent). Almost ten times as much of their land is within 100 km of a seacoast or navigable river (56 versus 6.5 percent), over a hundred times as much of their land is subject to seasonal frost (88 versus 0.6 percent), and only a tiny fraction of it is subject to high-level malaria (0.1 versus 43 percent). When multiplied by the reduced-form parameter estimates, the difference in malaria prevalence has by far the greatest effect, accounting for a 74 percent lower level of real income. The difference in seasonal frost prevalence accounts for a 16 percent lower level, and the difference in coastal location accounts for 15 percent lower income.

The remaining tables provide single-equation regressions, as a robustness check on the system results. Regressing income directly on all the exogenous variables of the system, as shown in Table 3, shows results that are broadly similar to those of the system as a whole, with seasonal frost and malaria prevalence being most closely associated with income. Regressing each of the other endogenous variables on all the exogenous variables, as shown in Table 4, also shows results that are consistent with the whole system. Both malaria prevalence and seasonal frost are significant and of the expected sign for all of the endogenous variables.

Table 5 provides regressions of income on the endogenous variables, using the exogenous ones as instruments, to compare with the final column of Table 1. These IV regressions are similar to those that would be done by researchers who are interested in the effects of potentially endogenous variables, abstracting from the question of what drives them. The results are roughly similar to those of the final column in Table 1, except that agricultural output enters significantly here and schooling has less significance. This kind of regression, however, begs the question of why some countries are able to have so much higher levels of these variables than others -- which is precisely the question that the full system of simultaneous equations aims to help answer.

Conclusions

This paper introduces the use of simultaneous equations to the question of how physical geography might affect economic growth. The empirical-growth literature has only recently begun to use geographic variables, partly because accurate globally-comparable data have only recently become available. Where these new geographic data are used in cross-country studies, they are employed either as direct regressors (i.e. Bloom and Sachs 1998, Gallup, Sachs and Mellinger 1999), or as instrumental variables for policy choices (i.e. Hall and Jones 1999, Acemoglu, Johnson and Robinson 1999).

In our simultaneous-equations approach, we test explicitly for the links between particular geographic factors and particular growth mechanisms. Understanding these links could help policymakers take geographic factors into account and circumvent their effects. Our main finding is that disease ecology, tropical climate and coastal location have had a large effect on income by facilitating improved health status, higher agricultural output, and greater urbanization, relative to other countries. These findings help us to see how geography might have influenced the location of economic growth in the past, while helping us to escape geographic determinism about the future: the effects of climate on health and agriculture are technological problems, with technological remedies.

Although countries with unfavorable climatic conditions have not (yet) succeeded in developing technologies to fully offset climate effects on health and agriculture, this could be due to their limited resources as much as the difficulty of the task. The R&D capacity of industrialized countries in health and agriculture is continuously improving, and directing some of that capacity to tropical problems could well unlock the economic potential of those regions. Indeed, we find that health and agricultural productivity are benefiting from technological improvements over time. But those improvements are not fast enough, and not sufficiently targeted to the needs of tropical countries, to offset the effects of differences in climatic conditions.

The persistent divergence of income levels between rich and poor nations, from a small gap at the start of the 20th century to a large gap at its end, highlights the need for much better understanding of what is missing in the lagging regions, and what can be done about it. The results presented here suggest that some important variables associated with higher income, notably higher-quality institutions and higher levels of schooling, could diffuse directly from more to less successful regions. But other variables, notably health status, agricultural productivity and urbanization, are rooted in physical geography and call for innovation rather than imitation, through R&D for locally-adapted technologies. The relative magnitudes we find are such that the diffusion of existing institutions alone is unlikely to achieve much narrowing of the income gap – whereas R&D targeted to tropical disease and tropical agriculture could have very large benefits, unlocking a virtuous circle of productivity growth and higher incomes.

References cited

Acemoglu, Daron, Simon Johnson and James A. Robinson, 2000. “The Colonial Origins of Comparative Development: An Empirical Investigation,” NBER Working Paper # 7771. Cambridge, MA: NBER.

Ades, Alberto F. and Edward L. Glaeser, 1999. “Evidence on Growth, Increasing Returns and the Extent of the Market.” *Quarterly Journal of Economics* 114(3, August): 1025-45.

Barro, Robert J. and Jong-Wha Lee, 2000. “International Data on Educational Attainment: Updates and Implications.” CID Working Paper 42 (www.cid.harvard.edu/cidwp/042.pdf). Cambridge, MA: Center for International Development, Harvard University, 34 pages (April).

Bloom, David and Jeffrey D. Sachs, 1998. “Geography, Demography, and Economic Growth in Africa,” *Brookings Papers on Economic Activity* 2: 207-295.

Doppelhofer, Germot, Ronald I. Miller and Xavier Sala-I-Martin (2000). “Determinants of Long-Term Growth: A Bayesian Averaging of Classical Estimates (BACE) Approach,” NBER Working Paper 7750. Cambridge, MA: NBER.

Easterly, William and Ross Levine, 1997. “Africa’s Growth Tragedy: Policies and Ethnic Divisions,” *Quarterly Journal of Economics*, 112 (4, November): 1213-1250.

Engerman, Stanley and Kenneth Sokoloff, 1997. “Factor Endowments, Institutions and Differential Paths of Growth among the New World Economies,” in Stephen Haber, ed., *How Latin America Fell Behind*, Stanford: Stanford University Press.

FAO, 1999. “FAOStat “ <http://faostat.fao.org/> and unpublished output series from Jan Poulisse (pers. comm.). Rome: Food and Agriculture Organization of the United Nations .

Gallup, John L. and Jeffrey D. Sachs, 2000. “The Economic Burden of Malaria.” CID Working Paper 52 (www.cid.harvard.edu/cidwp/052.pdf). Cambridge, MA: Center for International Development, Harvard University, 22 pages (July).

Gallup, John Luke, Jeffrey D. Sachs, and Andrew Mellinger, 1999. “Geography and Economic Development,” *International Regional Science Review* 22 (2, August): 179-232. (Reprinted from *Annual World Bank Conference on Development Economics 1998*, Boris Pleskovic and Joseph E. Stiglitz, eds. Washington, DC: The World Bank.)

Hall, Robert E. and Charles I. Jones, 1999. “Why Do Some Countries Produce so Much More Output per Worker than Others?” *Quarterly Journal of Economics*, 114 (1, February): 83-116.

International Panel on Climate Change, 1999. IPCC Data Distribution Data Centre CD-ROM, April (http://ipcc-ddc.cru.uea.ac.uk).

Jorgenson, Dale W., 1961. “The Development of a Dual Economy.” *The Economic Journal*, 71(282, June): 309-334.

Kamarck, Andrew M. (1976), *The Tropics and Economic Development: A Provocative Inquiry into the Poverty of Nations*. Baltimore: Johns Hopkins.

Knack, Stephen and Philip Keefer, 1995. "Institutions and Economic Performance: Cross-Country Tests Using Alternative Institutional Measures". *Economics and Politics,* 7 (3, November): 207-227.

Mankiw, N. Gregory, David Romer and David N. Weil (1992), “A Contribution to the Empirics of Economic Growth.” *Quarterly Journal of Economics* 107(2, May): 407-437.

Masters, William A. and Margaret S. McMillan, 2000. “Climate and Scale in Economic Growth.” CID Working Paper 48 (www.cid.harvard.edu/cidwp/048.pdf). Cambridge, MA: Center for International Development, Harvard University.

Masters, William A. and Kieth D. Wiebe, 2000. “Climate and Agricultural Productivity,” Center for International Development, Harvard University, October.

Matsuyama, Miminori, 1992. “Agricultural Productivity, Comparative Advantage and Economic Growth.” *Journal of Economic Theory* 58 (2, December): 317-334.

McCarthy, F. Desmond, Holger Wolf and Yi Wu, 2000. “Malaria and Growth.” Mimeo: The World Bank, 24 pages.

McMillan, Margaret, 2000. “Why Kill the Golden Goose? A Political Economy Model of Export Taxation.” *Review of Economics and Statistics*, forthcoming.

NRCS, 1999. *World Soil Resources database* <www.nhq.nrcs.usda.gov/WSR/>. Washington, DC: Natural Resources Conservation Service, USDA.

Ranis, Gustav and John C.H. Fei, 1961. “A Theory of Economic Development.” *The American Economic Review* 51(4, September): 533-565.

Sachs, Jeffrey D., 2000. “Tropical Underdevelopment,” Center for International Development, Harvard University, September.

Solow, Robert M., 1956. “A Contribution to the Theory of Economic Growth.” *Quarterly Journal of Economics* 70(1, February): 65-94.

Solow, Robert M., 1957. “Technical Change and the Aggregate Production Function.” *Review of Economics and Statistics* 39(3, August): 312-20.

Smith, Adam, 1776/1976. *An Inquiry into the Nature and Causes of the Wealth of Nations.* Chicago: University of Chicago Press.

United Nations, 1996. *World Population Prospects 1950-2050, revised*. New York: United Nations.

USGS, 1999. "Global Land Cover Characterization." U.S. Geological Survey, the University of Nebraska-Lincoln, and the Joint Research Centre of the European Commission <http://edcwww.cr.usgs.gov/landdaac/glcc/glcc.html>.

Weber, Max, 1905/1992. *The Protestant Ethic and the Spirit of Capitalism.* New York: Routledge.

Wiebe, K., M. Soule, C. Narrod and V. Breneman, 2000. "Resource Quality and Agricultural Productivity: A Multi-Country Comparison." Selected paper presented at the annual meetings of the AAEA, July. Washington: ERS, USDA (16 pp.).

WHO, 1967. "Malaria Eradication in 1966," *WHO Chronicle* 21 (9, September):373-388.

Table 1. Regression results in a system of simultaneous equations

	(1)	(2)	(3)	(4)	(5)	(6)
dependent variable:	ag.output/cap.	inf.mort.rate	schooling	instit.qual.	urbanization	income
indep. var.:	[ln(agout/cap)]	[ln(imr)]	[ln(ave.yrs.)]	[ln(icrg80)]	[ln(pct. urb.)]	[ln(rgdpch)]
ag.output/cap.[ln(agoutput/cap)]					0.562***	0.071
					(0.115)	(0.062)
inf.mort.rate [ln(imr)]			-0.405***	-0.134*		-0.002
			(0.085)	(0.071)		(0.112)
schooling [ln(ave.yrs.)]						0.457***
						(0.076)
instit.qual. [ln(icrg80)]						0.862***
						(0.162)
urbanization [ln(pct. urban)]						0.644***
						(0.066)
income [ln(rgdpch)]		-0.444***	0.287***	0.197***	0.122	
		(0.046)	(0.081)	(0.063)	(0.083)	
ag.land/cap.[ln(landag/cap)]	0.146***					
	(0.014)					
LQI [ln(lqiigbp2)]	0.024**					
	(0.009)					
frost [ln(pct. of land)]	0.040***					
	(0.008)					
precip. [ln(rain)]	0.054					
	(0.035)					
malaria prevalence [ln(malhi66)]	-0.157***	0.149***				
	(0.008)	(0.014)				
coastal [ln(pct. of land)]					0.058***	
					(0.008)	
% population catholic				-0.001***		
				(0.000)		
% population muslim				0.000		
				(0.001)		
% population protestant				0.002***		
				(0.001)		
y65	0.029	-0.076	-0.017	-0.038	0.066	0.021
	(0.066)	(0.058)	(0.076)	(0.042)	(0.085)	(0.060)
y70	0.075	-0.148**	0.025	-0.093**	0.131	0.036
	(0.065)	(0.058)	(0.076)	(0.041)	(0.085)	(0.061)
y75	0.126*	-0.263***	0.016	-0.139***	0.185**	0.056
	(0.065)	(0.059)	(0.076)	(0.042)	(0.086)	(0.066)
y80	0.143**	-0.347***	0.115	-0.168***	0.247***	0.017
	(0.065)	(0.061)	(0.077)	(0.043)	(0.089)	(0.070)
y85	0.114*	-0.568***	0.075	-0.208***	0.357***	-0.056
	(0.065)	(0.060)	(0.081)	(0.049)	(0.089)	(0.084)
y90	0.146**	-0.712***	0.104	-0.234***	0.392***	-0.098
	(0.065)	(0.061)	(0.086)	(0.055)	(0.090)	(0.092)
Constant	-8.233***	8.054***	0.541	0.825	7.068***	4.072***
	(0.220)	(0.318)	(0.966)	(0.755)	(1.570)	(0.944)
Observations	499	499	499	499	499	499

Note: Estimation method is 3SLS. Standard errors are in parentheses. Asterisks on coefficients represent * significant at 10%; ** significant at 5%; *** significant at 1%.

Table 2. Reduced form parameters computed from regression coefficients

endogenous variable: *exog. var.:*	(1) ag.output/cap. [ln(agoutput/cap)]	(2) inf.mort.rate [ln(imr)]	(3) schooling [ln(ave.yrs.)]	(4) instit.qual. [ln(icrg80)]	(5) urbanization [ln(pct. urban)]	(6) income [ln(rgdpch)]
ag.land/cap.[ln(landag/cap)]	0.146	-0.058	0.061	0.033	0.098	0.130
LQI [ln(lqiigbp2)]	0.024	-0.009	0.010	0.005	0.016	0.021
frost [ln(pct. of land)]	0.040	-0.016	0.017	0.009	0.027	0.036
precip. [ln(rain)]	0.054	-0.021	0.022	0.012	0.036	0.048
malaria prevalence [ln(malhi66)]	-0.157	0.252	-0.169	-0.080	-0.117	-0.233
coastal [ln(pct. of land)]	0.000	-0.034	0.036	0.020	0.067	0.077
% population catholic	0.000	0.001	-0.001	-0.001	0.000	-0.002
% population muslim	0.000	0.000	0.000	0.000	0.000	0.000
% population protestant	0.000	-0.002	0.002	0.003	0.000	0.004
y65	0.029	-0.129	0.070	0.003	0.097	0.120
y70	0.075	-0.266	0.209	-0.005	0.205	0.265
y75	0.126	-0.443	0.311	0.000	0.305	0.405
y80	0.143	-0.576	0.496	0.011	0.390	0.516
y85	0.114	-0.796	0.545	0.000	0.484	0.515
y90	0.146	-0.967	0.660	0.009	0.544	0.574
Constant	-8.233	4.783	0.718	1.635	3.340	7.366

Note: Computed from regression coefficients in Table 1, by matrix inversion: the parameters shown are $[(\mathbf{I}\text{-}\mathbf{A})^{-1}\mathbf{B}]'$, where **A'** is the first six rows of Table 1 and **B'** are the remaining rows, so that $\mathbf{y}=\mathbf{Ay}+\mathbf{Bz}$, and hence $\mathbf{y} = [(\mathbf{I}\text{-}\mathbf{A})^{-1}\mathbf{B}]\mathbf{z}$.
s

Table 2a. Mean values of exogenous variables and their reduced-form link to income

Underlying exogenous variable	(units)	Mean for high-inc. countries (n=154)	Mean for all other countries (n=345)	Effect on income of change from HIC to other countries' level
ag.land/cap.	(ha/pers)	0.62	1.22	9.30%
LQI	(% of land)	23.40%	8.70%	-2.10%
frost	(% of land)	88.00%	0.60%	-16.10%
precip.	(mm)	807	1093	1.50%
malaria prevalence	(% of land)	0.10%	43.40%	-73.80%
coastal	(% of land)	56.30%	6.50%	-15.30%
% population catholic	(% of pop.)	40.90%	43.90%	-0.50%
% population muslim	(% of pop.)	0.90%	24.10%	0.00%
% population protestant	(% of pop.)	30.10%	8.10%	-7.50%

Note: Computed from reduced-form parameters in Table 2, plus mean values for subsamples of high-income and other countries, as classified by the World Bank's *World Development Indicators 1999.* High-income countries in the estimation sample are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Israel, Italy, South Korea, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, U.K. and USA.

Table 3. Single-equation regression of income on its exogenous determinants

	(1)	(2)
dependent variable:	*income [ln(rgdpch)]*	*income [ln(rgdpch)]*
indep. var.:	without AR(1)	with AR(1)
ag.land/cap.[ln(landag/cap)]	0.075***	0.135***
	(0.009)	(0.017)
LQI [ln(lqiigbp2)]	0.015**	0.009
	(0.007)	(0.009)
frost [ln(pct. of land)]	0.099***	0.051***
	(0.006)	(0.009)
precip. [ln(rain)]	0.124***	0.141***
	(0.031)	(0.033)
malaria prevalence [ln(malhi66)]	-0.175***	-0.179***
	(0.007)	(0.011)
coastal [ln(pct. of land)]	0.061***	0.064***
	(0.005)	(0.007)
% population catholic	0.004***	0.004***
	(0.000)	(0.001)
% population muslim	0.000	0.001
	(0.001)	(0.001)
% population protestant	0.005***	0.008***
	(0.001)	(0.001)
y65	0.113***	0.122***
	(0.033)	(0.007)
y70	0.274***	0.289***
	(0.033)	(0.011)
y75	0.419***	0.430***
	(0.033)	(0.013)
y80	0.521***	0.512***
	(0.033)	(0.015)
y85	0.563***	0.530***
	(0.033)	(0.017)
y90	0.615***	0.595***
	(0.033)	(0.020)
Constant	6.630***	6.651***
	(0.217)	(0.248)
Observations	499	499
Number of groups (countries)	75	75

Note: Estimation method is feasible generalized least squares, allowing heteroskedasticity across countries. Country-specific AR(1) autocorrelation over time is allowed for the second column only. Heteroskedasticity-consistent standard errors are in parentheses. Asterisks on coefficients represent * significant at 10%; ** significant at 5%; *** significant at 1%

Table 4. Single-equation regressions of endogenous variables on exogenous variables

dependent variable: *indep. var.:*	(1) ag.output [ln(ag.output)]	(2) urbanization [ln(pct. urban)]	(3) instit.qual. [ln(icrg80)]	(4) inf.mort.rate [ln(imr)]	(5) schooling [ln(ave.yrs.)]
ag.land/cap.[ln(landag/cap)]	-0.162***	0.050***	0.005***	-0.031***	0.02
	(0.020)	(0.011)	(0.001)	(0.011)	(0.015)
LQI [ln(lqiigbp2)]	0.072***	0.047***	-0.003	-0.015***	0.096***
	(0.018)	(0.004)	(0.004)	(0.006)	(0.015)
frost [ln(pct. of land)]	0.112***	0.019***	0.052***	-0.024***	0.044***
	(0.014)	(0.007)	(0.002)	(0.009)	(0.009)
precip. [ln(rain)]	-0.132***	-0.144***	0	-0.062**	-0.109***
	(0.034)	(0.022)	(0.001)	(0.025)	(0.042)
malaria prevalence [ln(malhi66)]	-0.139***	-0.107***	-0.063***	0.191***	-0.073***
	(0.016)	(0.008)	(0.002)	(0.011)	(0.010)
coastal [ln(pct. of land)]	-0.002	0.084***	-0.006***	-0.030***	0.044***
	(0.007)	(0.005)	(0.001)	(0.005)	(0.004)
% population catholic	-0.001	0.006***	-0.004***	0.000	0.001
	(0.001)	0.000	0.000	(0.001)	(0.001)
% population muslim	-0.004***	0.004***	-0.004***	0.004***	-0.009***
	(0.001)	(0.001)	0.000	(0.001)	(0.001)
% population protestant	-0.008***	0.004***	0.001***	-0.007***	0.004***
	(0.001)	(0.001)	0.000	(0.001)	(0.001)
y65	0.087***	0.082***	-0.001***	-0.118***	0.074***
	(0.007)	(0.006)	0.000	(0.006)	(0.010)
y70	0.203***	0.174***	-0.002***	-0.257***	0.189***
	(0.010)	(0.008)	0.000	(0.009)	(0.014)
y75	0.310***	0.261***	-0.003***	-0.436***	0.279***
	(0.012)	(0.010)	0.000	(0.011)	(0.017)
y80	0.405***	0.341***	-0.003***	-0.554***	0.429***
	(0.014)	(0.011)	0.000	(0.013)	(0.019)
y85	0.472***	0.418***	-0.004***	-0.803***	0.502***
	(0.015)	(0.013)	0.000	(0.015)	(0.021)
y90	0.546***	0.478***	-0.005***	-0.976***	0.607***
	(0.017)	(0.014)	(0.001)	(0.017)	(0.023)
Constant	7.249***	3.797***	1.864***	5.101***	1.563***
	(0.289)	(0.163)	(0.018)	(0.173)	(0.303)
Observations	499	499	499	499	499
Number of group(iso3166)	75.000	75.000	75.000	75.000	75.000

Note: Estimation method is feasible generalized least squares, allowing heteroskedasticity across countries and country-specific AR(1) autocorrelation over time. Heteroskedasticity-consistent standard errors are in parentheses. Asterisks on coefficients represent * significant at 10%; ** significant at 5%; *** significant at 1%

Table 5. Single-equation IV regression of income on endogenous variables

Dependent variable:	income [ln(rgdpch)]	
Estimation method:	2SLS	GMM
ag.output/cap.[ln(agoutput/cap)]	0.182**	0.248***
	(0.079)	(0.072)
instit.qual. [ln(icrg80)]	0.839***	0.980***
	(0.192)	(0.202)
urbanization [ln(pct. urban)]	0.703***	0.741***
	(0.078)	(0.074)
inf.mort.rate [ln(imr)]	-0.106	0.055
	(0.130)	(0.131)
schooling [ln(ave.yrs.)]	0.170*	0.209**
	(0.090)	(0.094)
y65	0.019	0.044
	(0.061)	(0.072)
y70	0.049	0.092
	(0.063)	(0.071)
y75	0.071	0.132*
	(0.070)	(0.073)
y80	0.064	0.124
	(0.075)	(0.077)
y85	-0.018	0.083
	-0.093	-0.092
y90	-0.051	0.078
	(0.104)	(0.104)
Constant	5.582***	5.028***
	(1.125)	(1.223)
Observations	499	499
R-squared	0.890	

Estimation method is 2SLS for column 1, and GMM for column 2 (implemented in Stata using ivgmm0.ado) Standard errors in parentheses. Asterisks are * significant at 10%; ** significant at 5%; *** significant at 1%