NBER WORKING PAPER SERIES

RUGGEDNESS: THE BLESSING OF BAD GEOGRAPHY IN AFRICA

Nathan Nunn
Diego Puga

Working Paper 14918
http://www.nber.org/papers/w14918

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
April 2009

We are grateful for valuable comments from Ann Carlos, Edward Glaeser, Larry Katz, James Robinson, Enrique Sentana, three anonymous referees, as well as seminar participants. Both authors thank the Canadian Institute for Advanced Research CIFAR for its support. Funding from the Social Sciences and Humanities Research Council of Canada, Spain's Ministerio de Educacion y Ciencia SEJ2006-09993, the Comunidad de Madrid (PROCIUDAD-CM), and the Centre de Recerca en Economia Internacional is gratefully acknowledged. The views expressed herein are those of the author(s) and do not necessarily reflect the views of the National Bureau of Economic Research.

Ruggedness: The Blessing of Bad Geography in Africa
Nathan Nunn and Diego Puga
NBER Working Paper No. 14918
April 2009
JEL No. N40,N50,O11,O13

ABSTRACT

There is controversy about whether geography matters mainly because of its contemporaneous impact on economic outcomes or because of its interaction with historical events. Looking at terrain ruggedness, we are able to estimate the importance of these two channels. Because rugged terrain hinders trade and most productive activities, it has a negative direct effect on income. However, in Africa rugged terrain afforded protection to those being raided during the slave trades. Since the slave trades retarded subsequent economic development, in Africa ruggedness has also had a historical indirect positive effect on income. Studying all countries worldwide, we find that both effects are significant statistically and that for Africa the indirect positive effect dominates the direct negative effect. Looking within Africa, we also provide evidence that the indirect effect operates through the slave trades.

Nathan Nunn
Department of Economics
Harvard University
1805 Cambridge Street
Cambridge, MA 02138
and NBER
nnunn@fas.harvard.edu

Diego Puga
IMDEA
Universidad Carlos III de Madrid, Dep. Economia
28903 Getafe
Spain
and CEPR
diego.puga@imdea.org

1. Introduction

Rugged terrain is tough to farm, costly to traverse, and often inhospitable to live in; yet in Africa, countries with a rugged landscape tend to perform better than flatter ones. To explain this paradox, this paper reaches back more than two centuries — to the slave trades.

In Africa, between 1400 and 1900, four simultaneous slave trades, across the Atlantic, the Sahara Desert, the Red Sea and the Indian Ocean, led to the forced migration of over 18 million people, with many more dying in the process (Africa's total population was roughly stable over this period at 50–70 million). The economies they left behind were devastated: political institutions collapsed, and societies fragmented. For African people fleeing this slave trade over the centuries, rugged terrain was a positive advantage. Enslavement generally took place through raids by one group on another, and hills, caves and cliff walls provided lookout posts and hiding places for those trying to escape. Today, however, that same geographical ruggedness is an economic handicap, making it expensive to transport goods, raising the cost of irrigating and farming the land, and simply making it more expensive to do business.

We exploit the historical importance of terrain ruggedness within Africa to inform the debate that has arisen about the importance of geography for economic development. While it is commonly agreed that geography can have important consequences for economic outcomes, there is a growing debate over the channel of causality. Some authors stress a direct contemporaneous channel whereby geography directly affects economic outcomes today. For instance, Gallup and Sachs (2001) and Sachs and Malaney (2002) claim that a disease-prone environment has substantial negative consequences for current income levels because it reduces productivity, lowers the incentives to invest in human capital, draws scarce resources towards medical care, and discourages foreign investment and tourism.[1] Alternatively, other authors stress an indirect channel whereby geography indirectly affects economic outcomes today through its past interactions with key historical events. For instance, Acemoglu, Johnson, and Robinson (2001) argue that the importance of a disease-prone environment for current income levels lies in the effect that it had on potential settler mortality during colonization. In areas were high mortality discouraged Europeans from settling, colonizers implemented poor institutions which adversely affected subsequent economic development.[2]

Generally, it is difficult to separate the direct/contemporaneous and the indirect/historical channels. A key obstacle is that the geographical features on which the literature has focused only affect the areas that were also subject to the historical events of interest. For instance, tropical

[1] Other geographical characteristics that have been linked to economic outcomes through a direct contemporaneous channel include proximity to the coast, and the prevalence of desert or tropical climate (Kamarck, 1976, Mellinger, Sachs, and Gallup, 2000, Sachs, 2001, Rappaport and Sachs, 2003).

[2] Other papers that argue for connections between the physical environment and economic outcomes through historical interactions include Engerman and Sokoloff (1997, 2002), Sokoloff and Engerman (2000), Diamond (1997), and Acemoglu, Johnson, and Robinson (2002).

diseases, today and historically, do not affect the parts of the world that were not colonized.[3] This obstacle is absent in the case of terrain ruggedness: the long-term, positive effect of ruggedness, through fending off the slave-traders, is concentrated in African countries, where the trade took place; while the contemporaneous, negative effect is universal. Thus, we are able to separately estimate, for one geographic characteristic, both the direct contemporaneous channel and the indirect historic channel. We can also identify the indirect historic channel by using estimates, constructed by Nunn (2008), of the number of slaves taken from each country in Africa. He combines historical shipping records with slave inventories reporting slave ethnicities, and finds that the slave trades had adverse effects on subsequent economic development because they weakened indigenous political structures and institutions, and promoted ethnic and political fragmentation. This is consistent with the ample historical evidence documenting the adverse long-term effects of Africa's slave trades.

We describe in section 2 how we measure terrain ruggedness (data sources for all other variables employed in the analysis are detailed in the appendix). Then, after introducing the econometric framework in section 3, we investigate the relationship between ruggedness and income in section 4. We find that both the direct and indirect effects of ruggedness on income exist and are statistically significant. The results are very robust. Looking within Africa, in section 5 we provide evidence that the indirect positive effect of ruggedness operates through the slave trades. We also estimate each of the coefficients for each of the channels implicit in the indirect effect of ruggedness. We find support for each of the underlying relationships: ruggedness negatively affects slave exports, and slave exports negatively affect the quality of domestic institutions, which is an important determinant of per capita income.

2. Terrain ruggedness

The adverse effects that rugged terrain has on economic outcomes are well established. Irregular terrain makes cultivation difficult. On steep slopes erosion becomes a potential hazard, and the control of water (e.g. irrigation) becomes much more difficult. According to the Food and Agriculture Organization (1993), when slopes are greater than 2 degrees, the benefits of cultivation often do not cover the necessary costs, and when slopes are greater than 6 degrees cultivation becomes impossible. In addition, because of the very high costs involved in earthwork, building costs are much greater when terrain is irregular (Rapaport and Snickars, 1999, Nogales, Archondo-Callao, and Bhandari, 2002). As well, transportation over irregular terrain is slower and more costly.[4]

[3] Because of these difficulties, few studies attempt to quantify or directly test for the relative importance of the two channels. One notable exception is Easterly and Levine (2003), who employ tests of over-identifying restrictions in an instrumental variables framework. They conclude that measures of tropics, germs, and crops do not explain economic development beyond their ability to explain institutional development. A related difficulty is that the physical environment is extremely persistent. An interesting exception is rainfall, which Miguel, Satyanath, and Sergenti (2004) use as an instrumental variable to investigate the effect of economic growth on the likelihood of civil conflict.

[4] A recent study by Allen, Bourke, and Gibson (2005) highlights these negative effects of irregular terrain within Papua New Guinea. The authors show that steep terrain not only makes the production of cash crops very difficult, but it also makes it much more costly or even impossible to transport the crops to the markets. The end result is that the populations living in these parts of Papua New Guinea have lower incomes and poorer health.

In Africa, we expect terrain ruggedness to also have beneficial effects by having helped areas avoid the negative long-term consequences of the slave trades. The most common method of enslavement was through raids and kidnapping by members of one ethnicity on another, or even between members of the same ethnicity (Northrup, 1978, Lovejoy, 2000). Rugged terrain afforded protection to those being raided during Africa's slave trades, provided caves for hiding, and provided the ability to watch the lowlands and incoming paths. African historians have documented many examples of this. For instance, Bah (1976) describes how "[t]hroughout time, caverns, caves and cliff walls have served as places of refuge for people. [...] There are many examples of this defensive system in Africa. At Ebarak (south- eastern Senegal), there are still traces left of a tata wall near a cave in which the Bassaris, escaping from Fulani raids, hid." Writing about what is now Mali, Brasseur (1968) explains that "[h]idden in the uneven terrain, they [the Dogon] were able to use the military crests and, as far as the techniques of war at the time were concerned, were impregnable."[5]

When measuring terrain ruggedness, our purpose is to have a measure that captures small-scale terrain irregularities, such as caverns, caves and cliff walls that afforded protection to those being raided during the slave trades. We do so by calculating the *terrain ruggedness index*, originally devised by Riley, DeGloria, and Elliot (1999) to quantify topographic heterogeneity in wildlife habitats providing concealment for preys and lookout posts. The main benefits of this measure are that it quantifies terrain irregularities at a very fine level and it was designed to capture precisely the type of topographic features we are interested in. Other measures that have been used by economists and political scientists are typically constructed to capture the presence of large-scale terrain irregularities, and mountains in particular.[6] Nevertheless, we show below that the results are robust to the use of alternative measures of terrain ruggedness.

Our starting point is GTOPO30 (US Geological Survey, 1996), a global elevation data set developed through a collaborative international effort led by staff at the US Geological Survey's Center for Earth Resources Observation and Science (EROS). Elevations in GTOPO30 are regularly spaced at 30-arc seconds across the entire surface of the Earth on a map using a geographic projection. The sea-level surface distance between two adjacent grid points on a meridian is half a nautical mile or, equivalently, 926 metres.

Figure 1 represents a few 30 by 30 arc-second cells, with each cell centred on a point on from the GTOPO30 elevation grid. The ruggedness calculation takes a point on the Earth's surface like

[5]For additional evidence, see Marchesseau (1945), Podlewski (1961), Gleave and Prothero (1971), Bah (1985, 2003), Cordell (2003), and Kusimba (2004).

[6]For example, Gerrard (2000) constructs a measure of the percentage of each country that is covered by mountains, which is used by Fearon and Laitin (2003), Collier and Hoeffler (2004) and others in studies of civil war and conflict. Ramcharan (2006) uses data from the Center for International Earth Science Information Network (2003) on the percentage of each country within different elevation ranges in an instrumental-variables analysis of how economic diversification affects financial diversification. An exception to the focus on large-scale terrain irregularities is the article by Burchfield, Overman, Puga, and Turner (2006), who construct measures of both small-scale and large-scale irregularities and show that they have opposite effects on the scatteredness of residential development in US metropolitan areas. Burchfield *et al.* (2006) measure small-scale terrain irregularities using the same terrain ruggedness index of Riley *et al.* (1999) that we use in this paper. Olken (2006) also uses small-scale terrain irregularities to compute a predicted measure of the signal strength of television transmissions to Indonesian villages in his study of the effects of television on social capital.

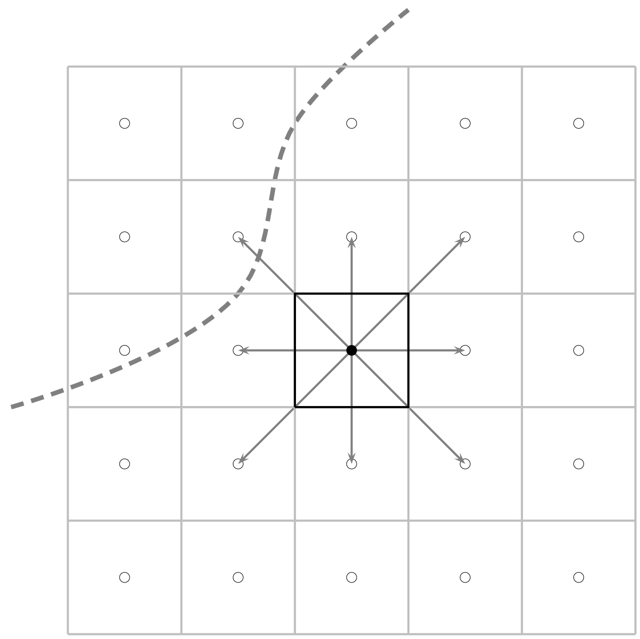

Figure 1: Schematic of the terrain ruggedness calculation

the one marked by a solid circle in the centre of figure 1 and calculates the difference in elevation between this point and the point on the grid 30 arc-seconds North of it (the hollow circle directly above it in the figure). The calculation is performed for each of the eight major directions of the compass (North, Northeast, East, Southeast, South, Southwest, West, and Northwest). The terrain ruggedness index at the central point of figure 1 is given by the square root of the sum of the squared differences in elevation between the central point and the eight adjacent points. More formally, let $e_{r,c}$ denote elevation at the point located in row r and column c of a grid of elevation points. Then the terrain ruggedness index of Riley *et al.* (1999) at that point is calculated as $\sqrt{\sum_{i=r-1}^{r+1} \sum_{i=c-1}^{c+1} (e_{i,j} - e_{r,c})^2}$. Finally, we average across all grid cells in the country not covered by water (taking into account when averaging the latitude-varying sea-level surface that corresponds to the 30 by 30 arc-second cell centred on each point) to obtain the average terrain ruggedness of the country's land area.

The units for the terrain ruggedness index correspond to the units used to measure elevation differences. In our calculation, ruggedness is measured in hundreds of metres of elevation difference for grid points 30 arc-seconds (926 metres on a meridian) apart. Examples of countries with an average ruggedness that corresponds to nearly level terrain are Netherlands (terrain ruggedness 0.037) and Mauritania(0.115). Romania (1.267) and Zimbabwe (1.194) have mildly rugged terrain on average. Countries with terrain that is moderately rugged include Italy (2.458) and Djibouti (2.432). Highly rugged countries include Nepal (5.043) and Lesotho (6.202). Basic summary statistics for our ruggedness measure and correlations with other key variables are reported in table 8 in the data appendix.

3. Econometric framework

We now develop our estimation strategy for investigating the relationship between ruggedness and income. As discussed, our starting hypothesis is that ruggedness has a direct negative effect on current income because it increases the costs of cultivation, building, and trade. This relationship can be written

$$y_i = \kappa_1 - \alpha r_i + \beta q_i + e_i \ , \tag{1}$$

where i indexes countries, y_i is income per capita, r_i is our measure of ruggedness, q_i is a measure of the efficiency or quality of the organization of society, κ_1, α and β are constants ($\alpha > 0$ and $\beta > 0$), and e_i is a classical error term (i.e., we assume that e_i is independent and identically distributed, drawn from a normal distribution, with a conditional expectation of zero).

Historical studies and the empirical work of Nunn (2008) have documented that Africa's slave trades adversely affected the political and social structures of societies. We capture this effect of Africa's slave trades with the following equation

$$q_i = \begin{cases} \kappa_2 - \gamma x_i + u_i & \text{if } i \text{ is in Africa,} \\ u_i & \text{otherwise,} \end{cases} \tag{2}$$

where x_i denotes slave exports, κ_2 and γ are constants ($\gamma > 0$), and u_i is a classical error term.

Historical accounts argue that the number of slaves taken from an area was reduced by the ruggedness of the terrain. This relationship is given by

$$x_i = \kappa_3 - \lambda r_i + v_i \ , \tag{3}$$

where κ_2 and λ are constants ($\lambda > 0$), and v_i is a classical error term.

Equations (1), (2) and (3) are the core relationships in our analysis. Our first approach is to combine all three by substituting, which gives

$$y_i = \begin{cases} \kappa_1 - \alpha r_i + \beta\gamma\lambda r_i + \kappa_4 + \zeta_i + \xi_i & \text{if } i \text{ is in Africa,} \\ \kappa_1 - \alpha r_i + \zeta_i & \text{otherwise,} \end{cases} \tag{4}$$

where $\kappa_4 \equiv \beta(\kappa_2 - \gamma\kappa_3)$, $\zeta_i \equiv e_i + \beta u_i$ and $\xi_i \equiv -\beta\gamma v_i$. Equation (4) summarizes the relationships between ruggedness, the slave trades, and current income. It illustrates the core hypothesis of the paper: that for non-African countries, the relationship between ruggedness and income only includes a negative direct effect $-\alpha$, but for African countries, in addition to the negative direct effect $-\alpha$, there is also a positive indirect effect $\beta\gamma\lambda$.

Guided by equation (4), we estimate the following relationship between ruggedness and income:

$$y_i = \beta_0 + \beta_1 r_i + \beta_2 r_i I_i^{\text{Africa}} + \beta_3 I_i^{\text{Africa}} + \varepsilon_i \ , \tag{5}$$

which is a more compact version of (4), using an indicator variable I_i^{Africa} that equals 1 if i is in Africa and 0 otherwise.

We also estimate a restricted version of equation (5) that forces the ruggedness-income relationship to be the same for all countries.

$$y_i = \beta_4 + \beta_5 r_i + \varepsilon_i \ . \tag{6}$$

Our predictions about the relationships between ruggedness, the slave trades, and income yield the following hypotheses for the estimates of (5) and (6):

Hypothesis 1. $\beta_1 < 0$ (ruggedness has a direct negative effect on income).

Hypothesis 2. $\beta_2 > 0$ (in Africa ruggedness has an additional positive effect).

Hypothesis 3. $\beta_1 < \beta_5$ (not accounting for hypothesis 2 biases the direct effect towards zero).

The first hypothesis, captured by the sign of β_1, is that ruggedness has a direct negative effect on income. The second hypothesis, which is core to our paper, is that in Africa ruggedness has an additional positive effect on income. The third hypothesis compares the estimated direct effects of ruggedness in the unrestricted and restricted equations. We expect that, since β_5 captures both the direct and indirect effects of ruggedness, it will be an upwards biased estimate of $-\alpha$, whereas β_1 will be a consistent estimate of $-\alpha$. From this it follows that β_5 is greater than β_1. The following section tests whether the data supports these three hypotheses.[7]

We have assumed throughout that the conditional expectation of each of the error terms in equations (1)–(3) is equal to zero. In this case, estimating equation (5) provides a consistent estimate of the direct and indirect effect of ruggedness. In practice, our assumptions rely on there not being variables that belong in any of the structural equations (1)–(3), but are omitted from our reduced form estimating equation (5). More specifically, our main coefficient of interest is β_2 in equation (5), which measures the differential effect of ruggedness for Africa. In order for an omitted variable to bias this estimate, it must be the case that, either the relationship between income and the omitted factor is different inside and outside of Africa, or that the relationship between the omitted factor and ruggedness is different inside and outside of Africa. For this reason, in our empirical analysis, we pay particular attention to identifying and including potentially omitted factors for which the relationship with either income or ruggedness is potentially different inside and outside of Africa.

Equation (5) illustrates the relationship between income and ruggedness, leaving slave exports in the background. Recall that we arrived at this equation by substituting both (3) and (2) into (1). In section 5 we bring slave exports to the foreground by instead only substituting (2) into (1) and estimating (3) separately. This gives us a relationship between income and both ruggedness (now only incorporating its direct effect) and slave exports:

$$y_i = \begin{cases} \kappa_1 - \alpha r_i + \beta\kappa_2 - \beta\gamma x_i + \zeta_i & \text{if } i \text{ is in Africa,} \\ \kappa_1 - \alpha r_i + \zeta_i & \text{otherwise.} \end{cases} \quad (7)$$

We test this relationship and (3) by estimating the following equations (note that for all non-African countries slave exports are zero, $x_i = 0$):

$$y_i = \beta_6 + \beta_7 r_i + \beta_8 r_i I_i^{\text{Africa}} + \beta_9 I_i^{\text{Africa}} + \beta_{10} x_i + \varepsilon_i \ , \quad (8)$$

$$x_i = \beta_{11} + \beta_{12} r_i + \epsilon \ . \quad (9)$$

Estimating (8) and (9) allows us to test four additional hypotheses:

Hypothesis 4. $\beta_{12} < 0$ (ruggedness negatively affects slave exports).

[7] We have implicitly assumed that β_2 is the same for all African countries. In section 4 we relax this assumption and allow the indirect effect of ruggedness to differ across the regions of Africa.

Hypothesis 5. $\beta_{10} < 0$ (slave exports negatively affect income).

Hypothesis 6. $\beta_8 = 0$ (once slave exports are taken into account, the effect of ruggedness is no different in Africa).

Hypothesis 7. $\beta_7 < 0$ (once slave exports are taken into account, the effect of ruggedness is negative).

Hypothesis 4 and 5 are that ruggedness deterred slave exports and that slave exports are negatively related to current income. Hypothesis 6 provides a way of testing whether the slave trades can fully account for the positive indirect effect of ruggedness within Africa. If the ruggedness-income relationship is different for Africa only because of the slave trades, then once we control for the effect of the slave trades on income, there should no longer be a differential effect of ruggedness for Africa. Hypothesis 7 is that once the indirect effect of ruggedness is taken into account by controlling for the slave trades, the direct effect of ruggedness can be correctly identified and should be negative.

While we have been able to obtain a good estimate of x_i in order to estimate equation (3) separately from (1) and (2), obtaining an appropriate estimate of q_i in order to also estimate (1) and (2) separately from each other is more difficult. This is because we expect slave exports to negatively affect current income levels through a variety of channels, many of which are difficult to measure empirically. Nevertheless, as a final step in our empirical strategy, we use the "rule of law" variable from the World Bank's *Worldwide Governance Indicators* database (Kaufmann, Kraay, and Mastruzzi, 2008) as a proxy for q_i to estimate equations (1) and (2) separately. This allows us to trace the three steps that together produce the differential effect of ruggedness in Africa: ruggedness deterred slave exports, which in turn have negatively affected domestic institutions and the functioning of societies, which in turn are important determinants of per capita income.

4. The direct and indirect effects of ruggedness

As a first step in our empirical analysis, we now estimate the common effect of ruggedness on income per person and its differential effect for Africa. Our baseline estimates of equation (5) are given in table 1. Looking first at column (1), when we estimate equation (5) by regressing income per person on ruggedness while allowing for a differential effect in African countries, we find empirical confirmation for hypotheses 1 and 2. The coefficient for ruggedness is negative and statistically significant (i.e., $\beta_1 < 0$ in equation (5)), while the coefficient for ruggedness interacted with an indicator variable for Africa is positive and statistically significant (i.e., $\beta_2 > 0$ in equation (5), as stated in hypothesis 2). As well, the magnitude of the indirect effect of ruggedness is larger than the direct effect of ruggedness. This suggests that for this geographic characteristic the indirect historic effect on income is at least as large as the direct contemporaneous effect.[8]

If we estimate the same equation, but restrict the effect of ruggedness on income to be the same for African and non-African countries, then we estimate a small negative coefficient for ruggedness

[8]We discuss the economic magnitudes of these effects in section 5.

Table 1: The direct and indirect effects of ruggedness

	Dependent variable: Log real GDP per person 2000					
	(1)	(2)	(3)	(4)	(5)	(6)
Ruggedness	-0.203 (0.093)**	-0.196 (0.094)**	-0.203 (0.078)***	-0.243 (0.092)***	-0.193 (0.074)***	-0.231 (0.077)***
Ruggedness $\cdot I^{\text{Africa}}$	0.393 (0.144)***	0.404 (0.146)***	0.406 (0.132)***	0.414 (0.157)***	0.302 (0.130)**	0.321 (0.127)**
I^{Africa}	-1.948 (0.220)***	-2.014 (0.222)***	-1.707 (0.327)***	-2.066 (0.324)***	-1.615 (0.300)***	-1.562 (0.415)***
Diamonds		0.017 (0.012)				0.028 (0.010)***
Diamonds $\cdot I^{\text{Africa}}$		-0.014 (0.012)				-0.026 (0.011)**
% Fertile soil			0.000 (0.003)			-0.002 (0.003)
% Fertile soil $\cdot I^{\text{Africa}}$			-0.008 (0.007)			-0.009 (0.007)
% Tropical climate				-0.007 (0.002)***		-0.009 (0.002)***
% Tropical climate $\cdot I^{\text{Africa}}$				0.004 (0.004)		0.006 (0.004)
Distance to coast					-0.657 (0.190)***	-1.039 (0.193)***
Distance to coast $\cdot I^{\text{Africa}}$					-0.291 (0.427)	-0.194 (0.386)
Constant	9.223 (0.143)***	9.204 (0.148)***	9.221 (0.194)***	9.514 (0.164)***	9.388 (0.142)***	9.959 (0.195)***
Observations	170	170	170	170	170	170
R^2	0.357	0.367	0.363	0.405	0.421	0.537

Notes: Coefficients are reported with robust standard errors in brackets. ***, **, and * indicate significance at the 1, 5, and 10 percent levels.

that is not significantly different from zero (coefficient -0.067 with standard error 0.082). This is consistent with hypothesis 3. The negative direct effect of ruggedness is biased upwards (i.e., towards zero) when the positive effect of ruggedness within Africa is not taken into account (i.e., β_5 in equation (6) is greater than β_1 in equation (5), as stated in hypothesis 3).[9]

Robustness with respect to omitted geographical variables

When interpreting our core results regarding the relationship between ruggedness and current economic outcomes, a possible source of concern is that the estimated differential effect of ruggedness within Africa may be driven, at least in part, by other geographical features. However, for an omitted variable to bias our estimated differential effect, it is not enough that the omitted variable is correlated with income and ruggedness. It must be the case that, either the relationship between the omitted factor and income is different within and outside of Africa, or the relationship

[9]This specification includes the Africa indicator variable. If this is also removed, the estimated ruggedness coefficient is 0.003 and the standard error is 0.082.

between the omitted factor and ruggedness is different within and outside of Africa. Thus, to deal with potentially omitted differential effects, we include in our baseline specification of column (1) both the control variable and an interaction of the control variable with our Africa indicator variable. By doing this we allow the effect of the control variable to differ for Africa.

A potentially confounding factor, which may have differential effects within and outside of Africa, is the curse of mineral resources (Sachs and Warner, 2001, Mehlum, Moene, and Torvik, 2006). If diamond deposits are correlated with ruggedness, and diamond production increases income outside of Africa, but decreases income within Africa because of poor institutions, then this could potentially bias the estimated differential effect of ruggedness.[10] Column (2) adds to our baseline specification of column (1) a control variable measuring carats of gem-quality diamond extracted per square kilometre 1958–2000 (see the appendix for details of how this and other geographical controls are constructed) as well as an interaction of this control with the Africa indicator variable. This provides weak evidence that the effect of diamonds is positive in general, but that for African countries there is a differential negative effect that nearly wipes out the general positive effect (however, neither effect is statistically significant). The inclusion of this control variable and its interaction with the Africa indicator variable does not alter our results regarding the relationship between ruggedness and current economic outcomes. We have also tried including measures of other mineral resources, oil reserves and gold in particular, again together with an African interaction term, but found no significant effects.

It is also possible that in general rugged areas have worse soil quality, but within Africa rugged areas have better soil quality. For example, the Rift Valley region of Africa is rugged but has very fertile soil. To control for this possibility, we construct a measure of the percentage of fertile soil in each country. This is defined as soil that is not subject to severe constraints for growing rain-fed crops in terms of either soil fertility, depth, chemical and drainage properties, or moisture storage capacity, and is based on the FAO/UNESCO Digital Soil Map of the World. In column (3), we add the measure of soil fertility and its interaction with the Africa indicator variable to our baseline specification. The results show that the differential effect of ruggedness remains robust to controlling for soil quality.

A related argument can be made about tropical diseases. If rugged areas are less prone to tropical diseases within Africa but not in the rest of the world, then this could potentially bias the estimated differential effect of ruggedness. To check for this possibility, in column (4) we add to our baseline specification a variable measuring the percentage of each country that has any of the four tropical climates in the Köppen-Geiger climate classification, as well as an interaction of this variable with the Africa indicator variable. We see that there is a statistically significant negative relationship between tropical climate and income, but that the effect is no different for African countries. Our core results are, once again, unchanged.[11]

[10] See Mehlum *et al.* (2006) and Robinson, Torvik, and Verdier (2006) for theory and empirical evidence supporting such a differential effect of resource endowments.

[11] If instead of looking at tropical diseases in general, we focus on malaria in particular by including an index of the stability of malaria transmission from Kiszewski, Mellinger, Spielman, Malaney, Sachs, and Sachs (2004) and the corresponding African interaction, our core results are also unchanged. The same is true if we include distance to the equator and the corresponding African interaction.

Table 2: Differential effect of ruggedness for Africa, alternative income and ruggedness measures

		Dependent variable:			
		Log real GDP per person 2000 (World Bank)	Log real GDP per person 2000 (Maddison)	Log real GDP per person 1950 (Maddison)	Average log real GDP per person 1950–2000 (Maddison)
Ruggedness measure:	Ruggedness	0.321 (0.127)**	0.250 (0.113)**	0.284 (0.129)**	0.284 (0.123)**
	Average slope	0.098 (0.044)**	0.076 (0.040)*	0.083 (0.047)*	0.084 (0.045)*
	Local std. dev. of elevation	1.105 (0.459)**	0.835 (0.414)**	0.919 (0.460)**	0.922 (0.443)**
	% highly rugged land	0.017 (0.006)***	0.014 (0.006)**	0.017 (0.006)***	0.017 (0.006)***
	Pop.-weighted ruggedness	0.726 (0.220)***	0.664 (0.206)***	0.393 (0.192)**	0.531 (0.190)***
	Observations	170	159	137	137

Notes: Each entry of the table reports the coefficient and robust standard errors for Ruggedness $\cdot I^{\text{Africa}}$ from the specification of column (6) in table 1, estimated using an alternative income measure as the dependent variable and an alternative measure of ruggedness. The alternative income measure is reported above the corresponding column, and the alternative ruggedness measure is reported to the left of the corresponding row. ***, **, and * indicate significance at the 1, 5, and 10 percent levels.

Motivated by the arguments of Rappaport and Sachs (2003) and others that coastal access is a fundamental determinant of income differences, in column (5) we control for the average distance (measured in thousands of kilometres) to the nearest ice-free coast for each country. As before, we also include an interaction of the distance variable with the African indicator variable. Our results remain robust. Finally, in column (6) we include all of the geographic controls and their corresponding interaction terms. We find again that our baseline results from column (1) are robust to controlling for other geographic characteristics that could have a differential effect in Africa.[12]

Robustness with respect to alternative income and ruggedness measures

We next consider a number of sensitivity checks to ensure that the findings documented to this point are in fact robust. First, one can think of many alternative measures of ruggedness. We have chosen to use a well-established measure of terrain ruggedness that was developed Riley *et al.* (1999) to quantify topographic heterogeneity that creates hiding places and outlook posts in wildlife habitats. The first robustness check that we perform is to check that our results hold with other measures of ruggedness. An obvious alternative measure of ruggedness is the average slope of the terrain. Thus, using the same GTOPO30 elevation data, we calculate the average uphill slope of the country's surface area. For every point on the 30 arc-seconds grid, we calculate the absolute

[12]Of independent interest is the relationship between ruggedness and our set of control variables. We do not find a significant relationship between ruggedness and either diamond production, soil fertility, or distance from the coast. We do find a negative relationship between ruggedness and the fraction of a country that has a tropical climate. As well, we do not find Africa to be significantly more or less rugged than the rest of the world. See table 8 for details.

value of the slope between the point and the eight adjacent points. The absolute values of the eight slopes are then averaged to calculate the mean uphill slope for each 30 by 30 arc-second cell. We then average across all grid cells in a country not covered by water to obtain the average uphill slope of the country's land area.[13]

Of course, there are many other ways to measure differences in elevation within short distances. We also calculate the standard deviation of elevation within the same eight-cell neighbourhood used to calculate the terrain ruggedness index and slope, and then average this across all cells within each country.

It is possible that what matters is having a large enough amount of sufficiently rugged terrain nearby, even if some portions of the country are fairly flat. To capture this logic, we calculate the percentage of a country's land area that is highly rugged (with a threshold set at 240 metres for the terrain ruggedness index calculated on the 30 arc-seconds grid, below which Riley *et al.*, 1999 classify terrain as being 'level' to 'intermediately rugged').

All of these measures of ruggedness treat all land in the country uniformly when averaging over cells to construct country averages. Thus, they do not capture the possibility that ruggedness may be more important (and thus should be given more weight) in areas that are more densely populated today. To check that our results are not sensitive to this characteristic of our terrain ruggedness measure, we construct an alternative, population-weighted measure of ruggedness. We start by calculating the ruggedness of each 30 by 30 arc-second cell but, in averaging this for each country, we weight ruggedness in each cell by the share of the country's population located in that cell. The population data are for 2000 and are from the *LandScan* data set (Oak Ridge National Laboratory, 2001).[14]

The other robustness check that we perform is a test of whether our results are robust when we consider income from other time periods. When looking at time periods earlier than 2000, we turn to data from Maddison (2007), which has much better historic coverage than the World Bank. In 2000, Maddison only has data for 159 countries, compared to 170 for the World Bank. But once one starts to move back in time, Maddison's coverage is much better than the World Bank's. For example, prior to 1980 the World Bank does not have data on real per capita PPP-adjusted GDP. Maddison has data for 137 countries as far back as back to 1950. We find that our results are robust using income from any year between 1950 and 2000. We report robustness checks using the natural logarithm of real gross domestic product per person in 1950 and in 2000, and its average (based on annual data) between 1950 and 2000, with Maddison's data.

We summarize the results from this barrage of robustness checks in table 2. Each cell reports the coefficient of Ruggedness $\cdot I^{\text{Africa}}$ from our baseline estimating equation (5), with our full set of controls included (i.e., the specification in column (6) in table 1). In total, we report 20 coefficients from 20 different regressions, each using a different combination of the available measures of

[13] Again, our calculations take into account the latitude-varying sea-level surface that corresponds to the 30 by 30 arc-second cell centred on each point.

[14] We prefer our baseline measure to this alternative measure because it is fully exogenous. In addition, our estimation strategy requires using a common measure to estimate the direct contemporaneous and indirect historical effects of ruggedness, and it is not clear that a measure based on current population weights is appropriate for the historical channel.

Table 3: Robustness with respect to influential observations

	Dependent variable: Log real GDP per person 2000				
	Omit 10 most rugged	Omit 10 smallest	Omit if $\lvert\text{DFBETA}\rvert > 2/\sqrt{N}$	Using ln(Ruggedness)	Box-Cox Trans. of Ruggedness
	(1)	(2)	(3)	(4)	(5)
Ruggedness	-0.202 (0.083)**	-0.221 (0.083)***	-0.261 (0.068)***	-0.171 (0.051)***	-0.249 (0.075)***
Ruggedness $\cdot I^{\text{Africa}}$	0.286 (0.133)**	0.188 (0.099)*	0.223 (0.116)*	0.234 (0.119)**	0.333 (0.142)**
I^{Africa}	-1.448 (0.454)***	-1.465 (0.405)***	-1.510 (0.406)***	-1.083 (0.394)***	-1.139 (0.391)***
Diamonds	0.073 (0.031)**	0.029 (0.010)***	0.026 (0.010)***	0.029 (0.012)**	0.027 (0.012)**
Diamonds $\cdot I^{\text{Africa}}$	-0.071 (0.031)**	-0.027 (0.011)**	-0.024 (0.010)**	-0.027 (0.012)**	-0.025 (0.012)**
% Fertile soil	-0.002 (0.003)	-0.002 (0.004)	-0.002 (0.003)	-0.003 (0.003)	-0.002 (0.003)
% Fertile soil $\cdot I^{\text{Africa}}$	-0.010 (0.008)	-0.005 (0.007)	-0.005 (0.007)	-0.008 (0.007)	-0.008 (0.007)
% Tropical climate	-0.010 (0.002)***	-0.010 (0.002)***	-0.009 (0.002)***	-0.009 (0.002)***	-0.009 (0.002)***
% Tropical climate $\cdot I^{\text{Africa}}$	0.006 (0.004)*	0.005 (0.004)	0.003 (0.003)	0.005 (0.004)	0.006 (0.004)
Distance to coast	-1.064 (0.208)***	-1.015 (0.197)***	-1.023 (0.192)***	-1.052 (0.206)***	-1.058 (0.199)***
Distance to coast $\cdot I^{\text{Africa}}$	-0.185 (0.400)	-0.180 (0.395)	-0.176 (0.397)	-0.216 (0.383)	-0.191 (0.383)
Constant	9.898 (0.206)***	9.936 (0.212)***	9.989 (0.188)***	9.631 (0.197)***	9.665 (0.193)***
Observations	160	160	164	170	170
R^2	0.520	0.545	0.564	0.527	0.533

Notes: Coefficients are reported with robust standard errors in brackets. ***, **, and * indicate significance at the 1, 5, and 10 percent levels.

income and ruggedness. The estimated positive differential effect of ruggedness is very robust. In fact, in all 20 regressions, we find that the differential effect of ruggedness within Africa is positive and statistically significant.

Robustness with respect to influential observations

Next, we check whether the results from table 1 are driven by some particularly influential outliers. Figure 2 shows a scatter plot of income per person against ruggedness for African countries (top panel) and non-African countries (bottom panel). In these plots of the raw data, one observes a positive relationship for African countries and a negative relationship for non-African countries. However, a number of observations appear as clear outliers in terms of their ruggedness. Our first

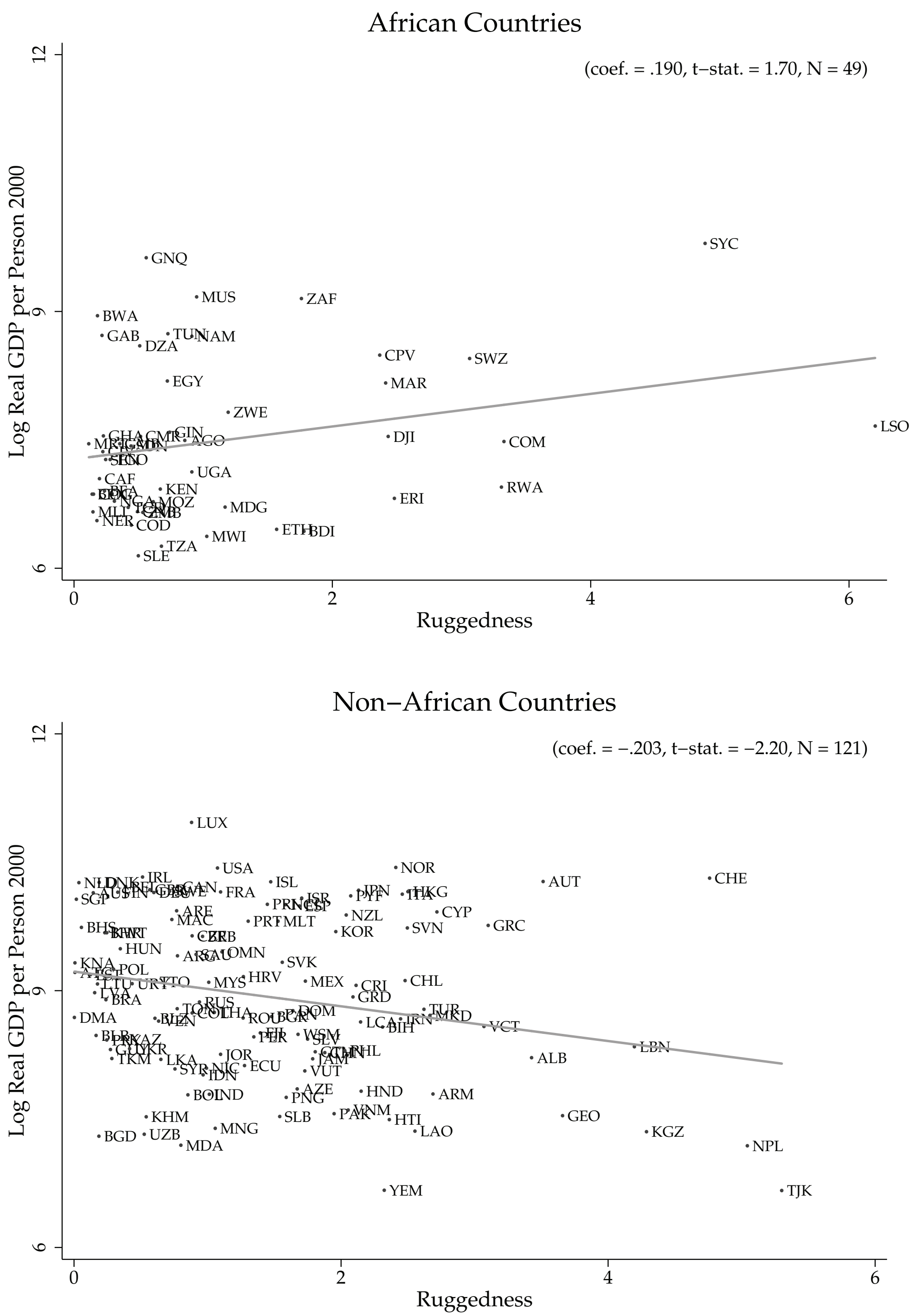

Figure 2: Income and ruggedness among African and non- African countries

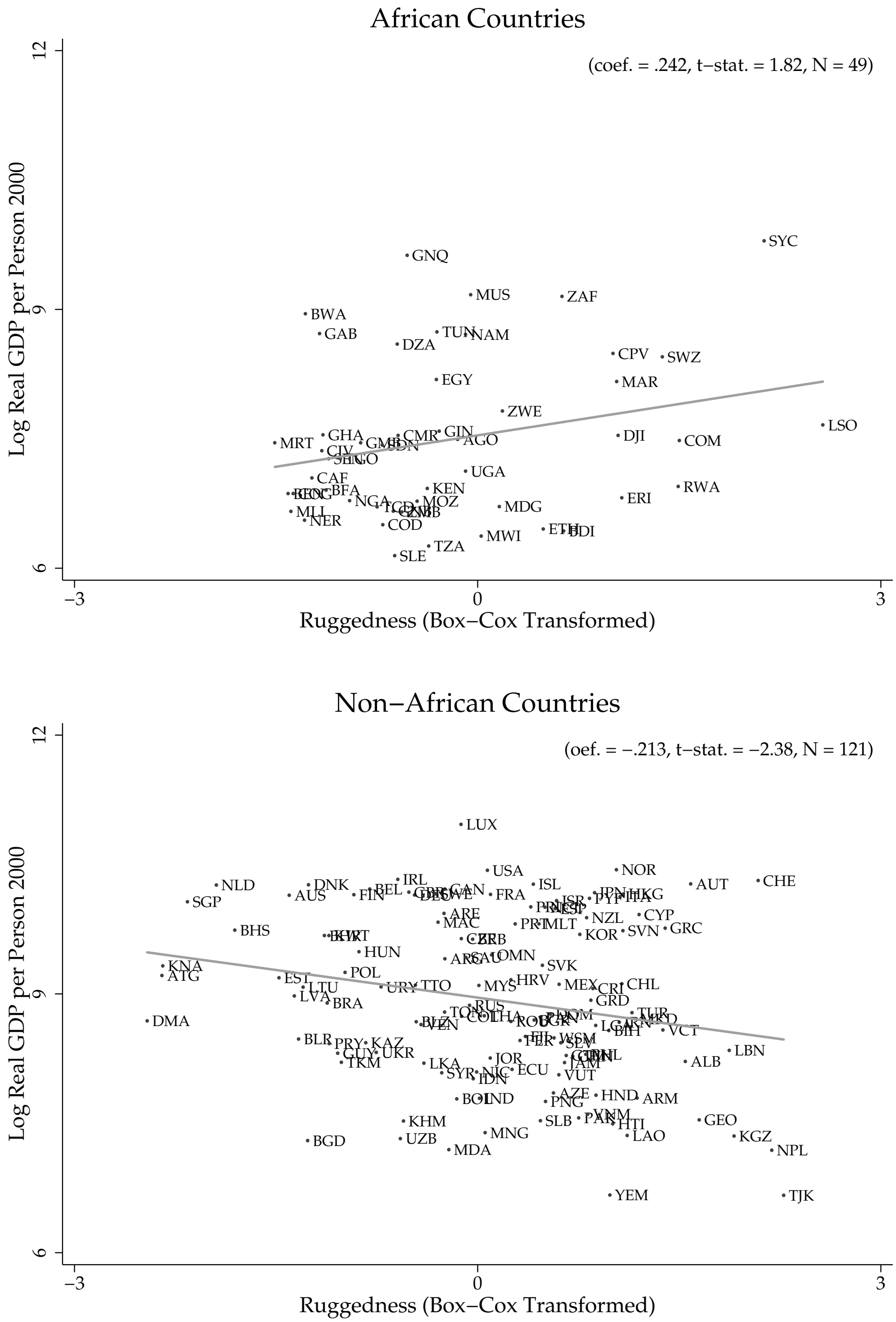

Figure 3: Income and ruggedness (Box-Cox transformed) among African and non-African countries

sensitivity check estimates our baseline specification, with our full set of control variables, after dropping the ten most rugged countries. The results are presented in column (1) of table 3.

In the scatter plot, one can also observe that small countries (based on land area) tend to have either unusually high (e.g., Seychelles, identified in the figure by its ISO 3166-1 code SYC) or unusually low ruggedness (e.g., Saint Kitts and Nevis, KNA). Given this, we perform a second robustness check where the ten smallest countries are omitted from the sample. The estimates are reported in column (2) of table 3.[15]

We next adopt a more systematic approach to deal with influential observations, and remove influential observations using each observation's DFBETA, which is a measure of the difference in the estimated coefficient for the ruggedness interaction (scaled by the standard error) when the observation is included and when it is excluded from the sample. Following Belsley, Kuh, and Welsch (1980), we omit all observations for which $|\text{DFBETA}_i| > 2/\sqrt{N}$, where N is the number of observations, in our case 170.[16] Results are presented in column (3) of table 3.

In all three of the regressions with omitted observations, the ruggedness coefficient remains negative and statistically significant, and the ruggedness interaction remains positive and statistically significant, confirming the existence of a differential effect of ruggedness within Africa.

The reason why, in figure 2, a small number of observations appear as particularly influential is because the ruggedness measure is skewed to the left, leaving a small number of observations with large values. We remedy this in two ways. First, we take the natural log of ruggedness and use this in the estimating equations. This draws in the outlying observations in the regression. The estimates of interest, reported in column (4), remain robust to this transformation. However, looking at the natural log of ruggedness variable, one finds that the measure is no longer left skewed, but it is now right skewed, with a small number of influential observations taking on very small values. Because of this, we pursue a second strategy where we perform a zero-skewness Box-Cox power transformation on the ruggedness variable to obtain a measure with zero skewness. The relationships between income and the zero-skewness ruggedness measure are shown in figure 3. It is evident that the income-ruggedness relationships using the zero-skewness measure do not feature influential, outlying observations. In addition, a different relationship within Africa and outside of Africa is still apparent in the scatter plots of the data. Estimates using the zero-skewness measure are reported in column (5). The estimates confirm the impression given by the figures. There is a positive and significant differential effect of ruggedness within Africa.

Do other African characteristics or colonial rule explain the differential effect of ruggedness?

A final possible source of concern is that the differential effect of ruggedness for Africa is not really an African effect. Perhaps it arises because the effect of ruggedness on income differs for areas with some geographic characteristic that happens to be particularly prevalent in Africa. For

[15] A related concern is that our results may be driven by "atypical" African countries, such as island countries or North African countries. Our results are also robust to omitting these "atypical" African countries from the sample.

[16] Using other measures and rules for the omission of influential observations, such as DFITS, Cook's distance or Welsch distance, provide very similar results.

Table 4: Considering differential effects of ruggedness by characteristics prevalent in Africa

	Dependent variable: Log real GDP per person 2000				
	(1)	(2)	(3)	(4)	(5)
Ruggedness	-0.259 (0.101)**	-0.322 (0.160)**	-0.374 (0.161)**	-0.386 (0.176)**	-0.543 (0.179)***
Ruggedness · I^{Africa}	0.357 (0.130)***	0.400 (0.155)***	0.360 (0.140)**	0.399 (0.203)**	0.435 (0.135)***
I^{Africa}	-1.814 (0.213)***	-1.977 (0.223)***	-1.818 (0.218)***	-1.740 (0.337)***	-1.994 (0.216)***
Ruggedness · % Tropical cl.	0.001 (0.002)		0.001 (0.002)	0.002 (0.002)	0.002 (0.002)
% Tropical climate	-0.007 (0.002)***		-0.007 (0.003)***	-0.007 (0.003)**	-0.010 (0.003)***
Ruggedness · % Fertile soil		0.003 (0.003)	0.003 (0.003)	0.004 (0.003)	0.002 (0.003)
% Fertile soil		-0.005 (0.004)	-0.003 (0.004)	-0.005 (0.004)	0.001 (0.003)
Ruggedness · $I^{\text{British col. orig.}}$				-0.089 (0.244)	
$I^{\text{British col. orig.}}$				0.062 (0.379)	
Ruggedness · $I^{\text{French col. orig.}}$				-0.108 (0.244)	
$I^{\text{French col. orig.}}$				-0.175 (0.511)	
Ruggedness · $I^{\text{Portuguese col. orig.}}$				0.361 (0.259)	
$I^{\text{Portuguese col. orig.}}$				-0.393 (0.467)	
Ruggedness · $I^{\text{Spanish col. orig.}}$				-0.105 (0.334)	
$I^{\text{Spanish col. orig.}}$				0.004 (0.538)	
Ruggedness · $I^{\text{Other European col. orig.}}$				-0.234 (0.328)	
$I^{\text{Other European col. orig.}}$				-0.703 (0.519)	
$I^{\text{French civil law}}$					-0.154 (0.222)
Ruggedness · $I^{\text{French civil law}}$					0.120 (0.127)
$I^{\text{Socialist law}}$					-1.181 (0.278)***
Ruggedness · $I^{\text{Socialist law}}$					0.194 (0.150)
$I^{\text{German civil law}}$					-0.087 (0.302)
Ruggedness · $I^{\text{German civil law}}$					0.528 (0.133)***
$I^{\text{Scandinavian law}}$					0.164 (0.221)
Ruggedness · $I^{\text{Scandinavian law}}$					0.666 (0.174)***
Constant	9.505 (0.168)***	9.427 (0.213)***	9.627 (0.223)***	9.681 (0.306)***	9.946 (0.232)***
Observations	170	170	170	170	170
R^2	0.404	0.363	0.408	0.430	0.559

Notes: Coefficients are reported with robust standard errors in brackets. ***, **, and * indicate significance at the 1, 5, and 10 percent levels.

instance, it could be that in countries where a large fraction of the territory experiences tropical climates, rugged areas are cooler, dryer, or even less prone to tropical diseases. If tropical climates are particularly prevalent in Africa (they characterize 34.0% of land in Africa compared with 19.3% of the rest of the world excluding Antarctica), perhaps the interaction between ruggedness and the Africa indicator is proxying for an interaction between ruggedness and tropical climates. Similarly, it could be that in countries where a large fraction of the territory is covered by dry unfertile soil, like desert, rugged areas are less arid. If areas with poor soil are particularly prevalent in Africa (fertile soil comprises 22.5% of the land in Africa compared with 25.3% in the rest of the world excluding Antarctica), perhaps the interaction between ruggedness and the Africa indicator is proxying for an interaction between ruggedness and poor soil quality.

We consider these possibilities in columns (1)–(3) of table 4, where we add to our baseline estimating equation variables measuring the percentage of each country with tropical climates and the percentage of each country with fertile soil (these can be seen as playing the same role as the Africa indicator), as well as interactions between ruggedness and these two variables (these can be seen as playing the same role as the interaction between ruggedness and the Africa indicator).[17] In columns (1) and (2) we include each of the two sets of controls one at a time, and in column (3) we include them together. The coefficients of interest, measuring the direct effect of ruggedness and the differential effect for Africa, change little and remain statistically significant.[18]

We next consider the possibility that our Africa indicator variable may be picking up the prevalence of colonial rule. In areas that were colonized, rugged terrain may have provided a way to defend against colonial rule. Since a greater proportion of countries in Africa, relative to the rest of the world, experienced colonial rule (within Africa 89% of the countries were colonized, while outside of Africa this figure is 44%), the differential effect of ruggedness in Africa may be biased by a differential effect of ruggedness in countries that were colonized.

We control for this possibility in columns (4) and (5) of table 4. In column (4), we include five indicator variables for the identity of a country's colonizer, with the omitted category being for countries that were not colonized.[19] We also include the set of colonizer indicator variables interacted with ruggedness. The differential effect of ruggedness remains positive and statistically significant.

Numerous studies have shown that differences in the legal origin of the colonizing powers is an important determinant of a variety of country characteristics, including financial development, labour market regulations, contract enforcement, and economic growth (La Porta, Lopez-de-Silanes, and Shleifer, 2008). Given the particular strong impact of colonial rule that works through legal origin, we also control directly for each country's legal origin, by including four legal origin

[17]The results are also robust if we use a measure of the proportion of a country's land that is desert, rather than the proportion with fertile soil.

[18]One could also think that certain countries, because of inferior access to technology or poor governance, are worse equipped to mitigate the direct contemporaneous effect of ruggedness. However, note that this would work *against* estimating a positive differential effect of ruggedness within Africa since access to technology and governance are likely to be worse on average in Africa. A further concern is that the tropical climate measure is potentially endogenous to ruggedness, since some areas may not be classified as tropical if they are rugged. A preferable measure would quantify how tropical a climate would be if it were not rugged. Using a country's distance from the equator as a proxy for this measure yields very similar results.

[19]The five categories for the identity of the colonizer are: British, Portuguese, French, Spanish, and other European.

indicator variables and their interactions ruggedness. The four indicators are for French, German, Scandinavian, and Socialist legal origins, with the omitted category being British legal origin. The positive differential effect of ruggedness remains when accounting for differences in countries' legal origins.

Differential effects of ruggedness within Africa

One concern with the results presented to this point is that we only allow the effect of ruggedness on economic outcomes to differ for African countries. We have also checked whether one also finds a positive and statistically significant differential effect of ruggedness within other parts of the world. Treating other continents in the exact same manner that we have treated Africa in equation (5) (including a continent indicator and an indicator interacted with ruggedness), we find that for no other continent is there a positive and statistically significant differential effect of ruggedness. In other words, the positive differential effect of ruggedness is *unique to Africa*, and is not found in North America, South America, Europe, Asia, or Oceania.

Having determined that the differential effect of ruggedness is specific to the African continent, we examine whether the strength of the effect differs across the regions within Africa in a manner that is consistent with the known history of the slave trades. Our argument is that ruggedness has a differential positive effect within Africa because no other continent was subject to the pressure of the slave trades that devastated Africa between 1400 and 1900. However, the pressure of the slave trades was not uniform across the continent. West Africa was the region most severely impacted by the slave trade, whereas North Africa was barely touched.[20] Thus, the logic of our core argument suggests that ruggedness should have a more beneficial effect within West Africa, where the threat of being enslaved was greatest, but within North Africa, where the slave trade raiding was nearly absent, the effect should be much smaller, and not very different from that in the rest of the world. To check this, we examine the five regions of Africa defined by Bratton and van de Walle (1997): West Africa, Central Africa, North Africa, South Africa, and East Africa. We construct an indicator variable for each region and then individually include each indicator variable and its interaction with ruggedness in equation (5). The estimates are reported in table 5. The results show that for West Africa and North Africa there is a statistically different effect of ruggedness relative to the average for all of Africa. Within West Africa, the positive effect of ruggedness is significantly larger. This is consistent with the positive effect of ruggedness working through the slave trade, and with West Africa being the region most severely impacted by the slave trade. In North Africa, where slave capture was almost completely absent, there is no positive effect of ruggedness.[21] The results also show that the other three regions lie between these two extremes. For these regions,

[20] The correlation between our measure of slave exports, described in detail in the next section, and a West Africa indicator variable is 0.53 and is statistically significant. The correlation between slave exports and a North Africa indicator variable is -0.30 and is also statistically significant. For all other African regions, the correlation between slave exports and a region indicator variable is not statistically different from zero.

[21] This is calculated by adding the coefficient of the North Africa interaction to the coefficient of the Africa interaction. This gives: $0.406 + -0.404 = -0.002$.

Table 5: Considering differential effects of ruggedness within Africa

	Dependent variable: Log real GDP per person 2000				
	(1)	(2)	(3)	(4)	(5)
Ruggedness	-0.203	-0.203	-0.203	-0.203	-0.203
	(0.093)**	(0.093)**	(0.093)**	(0.093)**	(0.093)**
Ruggedness $\cdot I^{\text{Africa}}$	0.312	0.408	0.409	0.406	0.448
	(0.159)**	(0.161)**	(0.147)***	(0.147)***	(0.179)**
I^{Africa}	-1.735	-1.844	-2.008	-2.046	-2.054
	(0.291)***	(0.229)***	(0.230)***	(0.222)***	(0.232)***
Ruggedness $\cdot I^{\text{West Africa}}$	0.532				
	(0.154)***				
$I^{\text{West Africa}}$	-0.635				
	(0.283)**				
Ruggedness $\cdot I^{\text{East Africa}}$		0.162			
		(0.274)			
$I^{\text{East Africa}}$		-0.760			
		(0.532)			
Ruggedness $\cdot I^{\text{Central Africa}}$			0.575		
			(1.197)		
$I^{\text{Central Africa}}$			0.020		
			(0.597)		
Ruggedness $\cdot I^{\text{North Africa}}$				-0.404	
				(0.131)***	
$I^{\text{North Africa}}$				1.465	
				(0.241)***	
Ruggedness $\cdot I^{\text{South Africa}}$					-0.200
					(0.195)
$I^{\text{South Africa}}$					0.592
					(0.519)
Constant	9.223	9.223	9.223	9.223	9.223
	(0.144)***	(0.144)***	(0.144)***	(0.144)***	(0.144)***
Observations	170	170	170	170	170
R^2	0.367	0.368	0.359	0.375	0.363

Notes: Coefficients are reported with robust standard errors in brackets. ***, **, and * indicate significance at the 1, 5, and 10 percent levels.

the positive differential effect of ruggedness is not statistically different from that for Africa as a whole.

Our finding that, across regions within Africa, the magnitudes of the differential effects of the ruggedness aligns closely with the intensity of the slave trades provides suggestive evidence of that the differential effect of ruggedness within Africa is intimately linked to the slave trades. In the following sections, we examine this directly, and provide additional evidence that this is in fact the case.

5. Do slave exports account for Africa's differential effect?

We now examine whether the slave trades can account for the differential effect of ruggedness within Africa. Our first step is to check for direct evidence that ruggedness provided protection against slave raiding. We do this using data from Nunn (2008) on the number of slaves exported from each country between 1400 and 1900 during Africa's four slave trades. The data uses historical shipping records to calculate slave exports, as well as slave inventories, reporting slave ethnicities, to assign exports to the country where slaves where captured (see the appendix and Nunn, 2008, for details). Because the variable is very skewed to the left and some countries have zero slave exports, we take the natural logarithm of one plus the measure, i.e. $\ln(1 + \text{slave exports/area})$. Using these data, we estimate equation (9) from section 3. Results are reported in columns (5)–(7) of table 6.

Column (5) of table 6 reports the unconditional relationship between ruggedness and slave exports among the 49 African countries in our sample. The estimate shows that there is a negative and statistically significant relationship between ruggedness and slave exports, and that ruggedness alone explains almost 30% of the variation in slave exports. This confirms hypothesis 4 (i.e., $\beta_{12} < 0$ in equation (9)). In columns (6) and (7), we include additional variables to address several potential concerns regarding the relationship between ruggedness and slave exports. We first include our baseline set of control variables. Among the four controls, the fraction of fertile soil is the only covariate that is statistically significant. The positive coefficient likely reflects that soil fertility was an important determinant of having a dense and sedentary initial population, which may have lead to more slaves being captured. In column (7), we include additional controls for other factors that may be important determinants of slave exports. We control directly for log population density in 1400. This is a particularly important characteristic, since it is possible that the reason fewer slaves were taken from countries with greater terrain ruggedness is that there were fewer people living in more rugged areas, and not because rugged terrain provided protection. The variable is not statistically significant. Since Nunn (2008) shows that slave exports are decreasing in the distance from each country to the closest slave market in each of the four slave trades, we also include these distances (measured in thousands of kilometres). The ruggedness coefficient remains negative and significant at the 1% level even after controlling for these additional factors.

Having established that rugged terrain deterred slave exports, we now turn to showing that slave exports are negatively related to current economic outcomes and that this fully accounts for the differential effect of ruggedness within Africa. In column (1) of table 6, we estimate equation

Table 6: The impact and determinants of slave exports

	Dep. variable: Log real GDP per person 2000				Dep. variable: Slave export intensity		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Slave export intensity	-0.203 (0.037)***	-0.222 (0.035)***	-0.206 (0.036)***	-0.214 (0.034)***			
Ruggedness	-0.203 (0.093)**	-0.169 (0.077)**	-0.231 (0.077)***	-0.220 (0.066)***	-1.330 (0.262)***	-1.326 (0.274)***	-1.115 (0.381)***
Ruggedness $\cdot I^{\text{Africa}}$	0.124 (0.152)		0.047 (0.143)				
I^{Africa}	-0.819 (0.317)***	-0.591 (0.222)***	-0.825 (0.356)**	-0.728 (0.354)**			
Diamonds			0.028 (0.010)***	0.028 (0.010)***		-0.005 (0.006)	-0.001 (0.007)
Diamonds $\cdot I^{\text{Africa}}$			-0.027 (0.010)**	-0.027 (0.010)***			
% Fertile soil			-0.002 (0.003)	-0.002 (0.003)		0.042 (0.015)***	0.039 (0.021)*
% Fertile soil $\cdot I^{\text{Africa}}$			0.000 (0.006)	0.001 (0.006)			
% Tropical climate			-0.009 (0.002)***	-0.009 (0.002)***		0.013 (0.009)	0.002 (0.012)
% Tropical climate $\cdot I^{\text{Africa}}$			0.009 (0.003)***	0.008 (0.003)***			
Distance to coast			-1.039 (0.194)***	-1.039 (0.194)***		0.154 (1.174)	-1.702 (1.665)
Distance to coast $\cdot I^{\text{Africa}}$			-0.162 (0.321)	-0.191 (0.343)			
Log pop. density 1400							0.289 (0.889)
Dist. Saharan slave market							-1.763 (1.013)*
Dist. Atlantic slave market							-1.005 (0.498)**
Dist. Red Sea slave market							-0.199 (0.700)
Dist. Indian slave market							-0.923 (0.497)*
Constant	9.223 (0.144)***	9.175 (0.127)***	9.959 (0.195)***	9.943 (0.195)***	5.572 (0.503)***	3.575 (1.251)***	25.050 (10.186)**
Observations	170	170	170	170	49	49	49
R^2	0.418	0.415	0.586	0.585	0.289	0.448	0.552

Notes: Coefficients are reported with robust standard errors in brackets. ***, **, and * indicate significance at the 1, 5, and 10 percent levels.

(8) from section 3. This is identical to equation (5) (for which we reported estimates in column (1) of table 1), except that slave exports are also included in the estimating equation. Column (3) reports the same estimation as column (1) except that we also include our baseline set of control variables from section 4 in the estimating equation. With or without the full set of controls, when slave exports are controlled for the differential effect of ruggedness within Africa disappears. The estimated coefficient on ruggedness $\cdot I^{\text{Africa}}$ is close to zero, and is no longer statistically significant. This confirms hypothesis 6 (i.e., $\beta_8 = 0$ in equation (8)), and provides support for the explanation that the differential effect of ruggedness arises because of the slave trades.

In columns (2) and (4), we re-estimate the specifications of, respectively, columns (1) and (3), leaving out the interaction between ruggedness and the Africa indicator variable. This confirms hypothesis 5, which formalizes the argument that current economic outcomes in Africa are worse in places more affected by the slave trades (i.e., $\beta_{10} < 0$ in equation (8)). We have already shown that once slave exports are taken into account the effect of ruggedness is no different within Africa than elsewhere (hypothesis 6). We can also see in columns (2) and (4) that this common effect, once slave exports are accounted for, is negative, which confirms hypothesis 7 (i.e., $\beta_7 < 0$ in equation (8)).

The estimates from table 6 can be used to calculate an alternative estimate of the indirect historic effect of ruggedness on income. The coefficients for slave export intensity from columns (1) and (3) provide estimates of the effect of slave exports on income, i.e., $\beta\gamma$ from equation (7). The coefficients for ruggedness from columns (5)–(7) provide estimates of λ from equation (1). Therefore, the product of the two coefficients provides an alternative estimate of the indirect historic effect of ruggedness $\beta\gamma\lambda$. Because this is a direct estimate of the effect of ruggedness that works through the slave trades, it is potentially more precise than our reduced form estimate (i.e., β_2 from equation (5)), which is based solely on the differential effect of ruggedness within Africa.

Consider the estimates with our baseline set of control variables, reported in columns (4) and (6). They give $\widehat{\beta\gamma} = -0.206$ and $\hat{\lambda} = -1.326$. Therefore, $\widehat{\beta\gamma}\hat{\lambda} = -0.206 \times -1.326 = 0.273$. We can compare this estimate to our reduced-form estimate reported in column (6) of table 1, which is 0.321. The indirect effect of ruggedness working through slave exports is almost identical to the reduced-form differential effect of ruggedness within Africa estimated in section 4. This provides reassuring confirmation that the reduced form differential effect of ruggedness within Africa is in fact being driven by the historic effect of ruggedness on Africa's slave trades.

Economic magnitude of the effects

To this point we have been focusing on the statistical significance of our estimated coefficients, ignoring the magnitude of their effects. Using the estimates from table 6, we now undertake a number of counterfactual calculations to show that the economic magnitudes of the indirect historic impact of ruggedness, working through the slave trades, is substantial.

We first consider the estimated magnitude of the impact of the slave trades on income. For context, consider a hypothetical African country with the mean level of slave exports and mean log real GDP per person among African countries. According to the estimates from column (3) of table 6, if this country was instead completely untouched by the slave trades, then its per capita income would increase by \$2,365, from \$1,784 to \$4,149.[22]

We next consider the magnitude of the historic benefit of ruggedness, which occurs through reduced slave exports. Consider the benefit of a one standard deviation increase in ruggedness from the average of 1.110 to 2.389. According to the estimates from column (6) of table 6, this reduces slave exports by $1.326 \times 1.279 = 1.70$, which is a 0.54 standard deviation decline in slave export intensity. This in turn increases log real GDP per person by \$747, from the average \$1,784 to \$2,531, which is a 0.37 standard deviation increase in log income per person.[23]

These effects are substantial, particularly given that we are considering the historic impact of one very specific geographic characteristic — terrain ruggedness — working through one historic event — the slave trades.

The effect of slave exports on income through rule of law

We have so far estimated the indirect effect of ruggedness on income, $\beta\gamma\lambda$, in two ways. First, by estimating the reduced-form relationship between income and ruggedness from equation (4) to obtain the combined differential effect of ruggedness within Africa $\widehat{\beta\gamma\lambda}$. Second, by estimating separately the effect of ruggedness on slave exports from equation (1) to obtain $\hat{\lambda}$ and the effect of slave exports on income of equation (7) to obtain $\widehat{\beta\gamma}$. A third alternative is to estimate the three equations (1)–(3) separately to obtain $\hat{\lambda}$, $\hat{\beta}$, and $\hat{\gamma}$ independently. One problem with this third alternative is that it is difficult to obtain an appropriate measure for q_i, which summarizes the different aspects of the organization of societies that are negatively affected by the slave trades. As a partial step in this direction, we use the "rule of law" variable from the World Bank's *Worldwide Governance Indicators* database (Kaufmann *et al.*, 2008). Estimates of equations (1) and (2) using this variable are reported in table 7.

The first two columns of the table report estimates of equation (1), which captures the effects of institutional quality, as proxied by the rule of law, on real per capita income in 2000. In column (1), we control for the Africa indicator variable only, and in column (2) we also control for our standard set of control variables and their interactions with the Africa indicator variable. The estimates show a strong negative, and statistically significant, relationship between the rule of law and per capita income. This result confirms the findings from a number of previous studies that stress the importance of governance and domestic institutions for long-term economic development (e.g., Acemoglu *et al.*, 2001).

Columns (3)–(5) of table 7 report estimates of equation (2), which models the relationship between slave exports and the quality of the organization of societies. The estimates of column

[22] This is calculated from: $\ln y' = \ln 1{,}784 - 0.206 \times (-4.09)$, where 4.09 is the mean slave export intensity measure among African countries (given in table 8), -0.206 is the estimated impact of slave exports on income (from column (3) of table 6), and y' denotes the counterfactual income, had the slave trades not occurred in the hypothetical country. Solving for y' gives \$4,149.

[23] This is calculated from: $\ln y' = \ln 1{,}784 - 0.206 \times (-1.326 \times 1.279)$, where 1.279 is the standard deviation of ruggedness among African countries (given in table 8), -1.326 is the estimated impact of ruggedness on slave exports (from column (6) of table 6), and -0.206 is the estimated impact of slave exports on income (from column (3) of table 6). Solving for y' gives \$2,531.

Table 7: The effect of slave exports on income through rule of law

	Dep. variable: Log real GDP per person 2000		Dep. variable: Rule of law		
	(1)	(2)	(3)	(4)	(5)
Rule of law	0.871 (0.044)***	0.813 (0.059)***			
Ruggedness	-0.034 (0.041)	-0.051 (0.039)			
I^{Africa}	-0.699 (0.131)***	-0.109 (0.352)	-0.509 (0.188)***	-1.001 (0.289)***	-1.104 (0.346)***
Slave export intensity			-0.086 (0.031)***	-0.065 (0.033)*	-0.065 (0.034)*
Diamonds		0.009 (0.014)		0.034 (0.008)***	0.025 (0.007)***
Diamonds $\cdot I^{\text{Africa}}$		-0.009 (0.015)		-0.033 (0.008)***	-0.023 (0.007)***
% Fertile soil		0.000 (0.002)		-0.002 (0.003)	0.003 (0.003)
% Fertile soil $\cdot I^{\text{Africa}}$		-0.015 (0.006)**		0.010 (0.005)*	0.005 (0.005)
% Tropical climate		-0.002 (0.001)		-0.009 (0.002)***	-0.011 (0.002)***
% Tropical climate $\cdot I^{\text{Africa}}$		0.003 (0.003)		0.004 (0.003)	0.005 (0.003)**
Distance to coast		-0.221 (0.174)		-0.995 (0.195)***	-0.438 (0.174)**
Distance to coast $\cdot I^{\text{Africa}}$		-0.576 (0.347)*		0.364 (0.294)	-0.197 (0.283)
$I^{\text{French civil law}}$					-0.554 (0.167)***
$I^{\text{French civil law}} \cdot I^{\text{Africa}}$					0.519 (0.239)**
$I^{\text{Socialist law}}$					-1.202 (0.214)***
$I^{\text{German civil law}}$					0.458 (0.282)
$I^{\text{Scandinavian law}}$					0.829 (0.200)***
Constant	8.783 (0.076)***	8.922 (0.159)***	0.218 (0.087)**	0.900 (0.195)***	1.035 (0.218)***
Observations	169	169	169	169	169
R^2	0.746	0.776	0.191	0.423	0.616

Notes: Coefficients are reported with robust standard errors in brackets. ***, **, and * indicate significance at the 1, 5, and 10 percent levels.

(3) control for the Africa indicator variable only. We include the Africa indicator to ensure that our estimated effect of slave exports on institutional quality is not estimated from the difference between Africa and the rest of the world. Because slave exports are zero for all countries outside of Africa, and because we always control for an Africa fixed effect, the estimated coefficient for slave exports is estimated from the relationship between slave exports and institutional quality within Africa only. In columns (4) and (5), we include additional control variables. We first include our baseline set of control variables and their interactions with the Africa indicator variable. Then, in column (5), we also add our legal origin fixed effects and their interactions with the Africa indicator variable.[24] The estimates provide strong support for the slave trade adversely affecting domestic institutions today. The coefficient for slave exports is negative and statistically significant.

Combining the estimated coefficients $\hat{\lambda} = -1.326$ from column (6) of table 6, $\hat{\beta} = 0.813$ from column (2) of table 7, and $\hat{\gamma} = -0.065$ from column (4) of table 7 yields $\hat{\lambda} \times \hat{\beta} \times \hat{\gamma} = 0.070$. Like the reduced-form estimate from column (6) of table 1, the indirect effect of ruggedness is found to be positive. However, the magnitude from the structural estimates is just under one fourth of the magnitude implied by the reduced-form estimate. This occurs because our structural estimates implicitly assume that the only effect of slave exports on income is through the rule of law. Any effect of the slave trade on per capita income that does not occur through our measured rule of law will not be captured when we estimate β and γ individually. This is not true however, for our estimate of the relationship between slave exports and income, $\widehat{\beta\gamma} = -0.206$. The relationship between slave exports and income implied by the individual estimates of β and γ is $\hat{\beta} \times \hat{\gamma} = 0.813 \times -0.065 = -0.053$. The difference between the two estimated magnitudes is consistent with the slave trade affecting income through channels other than the rule of law. Exploring such channels is the subject of ongoing research. For instance, the recent results of Nunn and Wantchekon (2008), which show that the slave trades had a negative effect on levels of trust 100 year after the end of the trade, provide evidence that the slave trades likely affect current income levels through a variety of additional channels other than the rule of law.

6. Conclusions

This paper contributes to the ongoing controversy about whether geography matters mainly because of its direct contemporaneous impact on economic outcomes or because of its interaction with historical events. The issue is not just a matter of intellectual curiosity. It is important for development policies, and has been the source of much recent debate. Researchers such as Jeffrey Sachs (2005) and others, who believe that geography matters primarily through a direct contemporaneous channel, argue that foreign aid and investment are needed to overcome the adverse geographic environments of poor countries. According to this view, with enough foreign

[24] Because our regression includes an Africa indicator variable, a full set of legal origin indicator variables, and interactions between them, non-African British common law countries constitute the omitted baseline category. Therefore, the differential effect (relative to this baseline) of the other legal origins for non-African countries is given by the coefficients of the legal origin indicator variables, while the differential effect of the other legal origins for African countries is given by the interaction of the legal origin indicators with the Africa indicator variable. Because African countries are only of either British or French legal origin, and none are of Socialist, German, or Scandinavian legal origin, indicators variables for these later three groups interacted with the Africa indicator variable are dropped from the regression.

aid the adverse effects of geography can be mitigated and alleviated, allowing the world's poorest countries to develop. Arguing against the effectiveness of foreign aid are those such as William Easterly (2006*a*,*b*, 2007), who believe that the importance of geography lies in its influence on past events, which have shaped the evolution of societies.[25] It is felt that the reason for underdevelopment has more to do with poor domestic governance, dysfunctional institutions, or poor economic policies, all of which have deep historical roots. According to this view, aid rather than being a panacea for underdevelopment, is largely ineffective and can even exacerbate poor governance, hampering economic development.[26]

By focusing on a dimension of geography, terrain ruggedness, which varies throughout the world and on a historical event, the slaves trades over the period 1400-1900, which is geographically confined to Africa, we are able to separately identify the direct contemporaneous channel and the indirect historic channel. We find a direct negative effect of ruggedness on income, which is consistent with irregular terrain making agriculture, building, and transportation more costly. We also find that rugged terrain had an additional effect in Africa during the 15th to 19th centuries: it afforded protection to those being raided during Africa's slave trades. By allowing areas to escape from the detrimental effects that the slave trades had on subsequent economic development, ruggedness also creates long-run benefits in Africa through an indirect historic channel. We show that this differential effect of ruggedness is found in Africa only, it cannot be explained by Africa's unique geographic environment, and it can be fully accounted for by Africa's the slave trades. On the whole, the results point to the importance of both a direct and an indirect channel through which ruggedness affects income.

References

Acemoglu, Daron, Simon Johnson, and James A. Robinson. 2001. The colonial origins of comparative development: An empirical investigation. *American Economic Review* 91(5):1369–1401.

Acemoglu, Daron, Simon Johnson, and James A. Robinson. 2002. Reversal of fortune: Geography and institutions in the making of the modern world income distribution. *Quarterly Journal of Economics* 117(4):1231–1294.

Allen, Bryant, R. Michael Bourke, and John Gibson. 2005. Poor rural places in Papua New Guinea. *Asia Pacific Viewpoint* 46(2):201–217.

Bah, Thierno Mouctar. 1976. The impact of wars on housing in pre-colonial black Africa. *African Environment* 76(3):3–18.

Bah, Thierno Mouctar. 1985. *Architecture Militaire Traditionalle et Poliorcétique dans le Soudan Occidental*. Yaondé, Cameroon: Editions CLE.

Bah, Thierno Mouctar. 2003. Slave-raiding and defensive systems south of lake Chad from the sixteenth to the nineteenth century. In Sylviane A. Diouf (ed.) *Fighting the Slave Trade: West African Strategies*. Athens, OH: Ohio University Press, 15–49.

[25]See in particular Easterly and Levine (2003).

[26]See Djankov, Montalvo, and Reynal-Querol (2005) for recent evidence on this "curse of aid".

Belsley, David A., Edwin Kuh, and Roy E. Welsch. 1980. *Regression Diagnostics: Identifying Influential Data and Sources of Collinearity*. New York, NY: John Wiley & Sons.

Brasseur, Georges. 1968. *Les Établissements Humains au Mali*. Dakar, Senegal: Mémoires de l'IFAN.

Bratton, Michael and Nicolas van de Walle. 1997. Political regimes and regime transitions in Africa, 1910–1994. Data Collection 6996, Inter-university Consortium for Political and Social Research.

Burchfield, Marcy, Henry G. Overman, Diego Puga, and Matthew A. Turner. 2006. Causes of sprawl: A portrait from space. *Quarterly Journal of Economics* 121(2):587–633.

Center for International Earth Science Information Network. 2003. *National Aggregates of Geospatial Data Collection: Population, Landscape, and Climate Estimates (PLACE)*. New York, NY: Center for International Earth Science Information Network (CIESIN), Columbia University.

Collier, Paul and Anke Hoeffler. 2004. Greed and grievance in civil war. *Oxford Economic Papers* 56(4):563–595.

Cordell, Dennis D. 2003. The myth of inevitability and invincibility: Resistance to slavers and the slave trade in Central Africa, 1850–1910. In Sylviane A. Diouf (ed.) *Fighting the Slave Trade: West African Strategies*. Athens, OH: Ohio University Press, 31–49.

Diamond, Jared. 1997. *Guns, Germs, and Steel*. New York, NY: W. W. Norton & Company.

Djankov, Simeon, Jose G. Montalvo, and Marta Reynal-Querol. 2005. The curse of aid. Working Paper 870, Universitat Pompeu Fabra.

Easterly, William. 2006*a*. *The White Man's Burden: Why the West's Efforts to Aid the Rest Have Done so Much Ill and so Little Good*. New York, NY: Penguin Press.

Easterly, William. 2006*b*. Reliving the 1950s: The big push, poverty traps, and takeoffs in economic development. *Journal of Economic Growth* 11(4):289–318.

Easterly, William. 2007. Was development assistance a mistake? *American Economic Review Papers and Proceedings* 97(2):328–332.

Easterly, William and Ross Levine. 2003. Tropics, germs, and crops: The role of endowments in economic development. *Journal of Monetary Economics* 50(1):3–39.

Engerman, Stanley L. and Kenneth L. Sokoloff. 1997. Factor endowments, institutions, and differential paths of growth among New World economies: A view from economic historians of the United States. In Stephen Harber (ed.) *How Latin America Fell Behind*. Stanford: Stanford University Press, 260–304.

Engerman, Stanley L. and Kenneth L. Sokoloff. 2002. Factor endowments, inequality, and paths of development among new world economies. Working Paper 9259, National Bureau of Economic Research.

Fearon, James D. and David Laitin. 2003. Ethnicity, insurgency, and civil war. *American Political Science Review* 97(1):75–90.

Fischer, Günther, Harrij van Velthuizen, Mahendra Shah, and Freddy Nachtergaele. 2002. *Global Agro-ecological Assessment for Agriculture in the 21st Century*. Laxenburg, Austria: Food and Agriculture Organization of the United Nations and International Institute for Applied Systems Analysis.

Food and Agriculture Organization. 1993. *Guidelines for Land-Use Planning*. Rome: Food and Agriculture Organization of the United Nations.

Food and Agriculture Organization. 2008. *ResourceSTAT*. Rome: Food and Agriculture Organization of the United Nations.

Gallup, John Luke and Jeffrey D. Sachs. 2001. The economic burden of malaria. *American Journal of Tropical Medicine and Hygiene* 64(1-2):85–96.

Gerrard, A. J. W. 2000. What is a mountain? Processed, The World Bank Development Research Group.

Gleave, M. B. and R. M. Prothero. 1971. Population density and 'slave raiding' – A comment. *Journal of African History* 12(2):319–324.

Kamarck, Andrew M. 1976. *The Tropics and Economic Development*. Baltimore, MD: John Hopkins University Press.

Kaufmann, Daniel, Aart Kraay, and Massimo Mastruzzi. 2008. Governance matters VII: Aggregate and individual governance indicators, 1996–2007. Policy Research Working Paper 4654, World Bank.

Kiszewski, Anthony, Andrew Mellinger, Andrew Spielman, Pia Malaney, Sonia Ehrlich Sachs, and Jeffrey Sachs. 2004. A global index of the stability of malaria transmission. *American Journal of Tropical Medicine and Hygiene* 70(5):486–498.

Kottek, Markus, Jürgen Grieser, Christoph Beck, Bruno Rudolf, and Franz Rubel. 2006. World map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift* 15(3):259–263.

Kusimba, Chapurukha M. 2004. Archaeology of slavery in East Africa. *African Archaeological Review* 21(2):59–88.

La Porta, Rafael, Florencio Lopez-de-Silanes, and Andrei Shleifer. 2008. The economic consequences of legal origins. *Journal of Economic Literature* 46(2):285–332.

La Porta, Rafael, Florencio Lopez-de-Silanes, Andrei Shleifer, and Robert Vishny. 1999. The quality of government. *Journal of Law, Economics and Organization* 15(1):222–279.

Lovejoy, Paul E. 2000. *Transformations in Slavery: A History of Slavery in Africa*. Second edition. Cambridge, UK: Cambridge University Press.

Maddison, Angus. 2007. *Contours of the World Economy, 1–2030 AD: Essays in Macroeconomic History*. Oxford: Oxford University Press.

Marchesseau, G. 1945. Quelques éléments d'ethnographie sur les Mofu du massif de Durum. *Bulletin de la Société d'Etudes Camerounaises* 10(1):7–54.

McEvedy, Colin and Richard Jones. 1978. *Atlas of World Population History*. Harmondsworth: Penguin Books.

Mehlum, Halvor, Karl Moene, and Ragnar Torvik. 2006. Institutions and the resource curse. *Economic Journal* 116(508):1–20.

Mellinger, Andrew, Jeffrey D. Sachs, and John Gallup. 2000. Climate, coastal proximity, and development. In Gordon L. Clark, Maryann P. Feldman, and Meric S. Gertler (eds.) *Oxford Handbook of Economic Geography*. Oxford, UK: Oxford University Press, 169–194.

Miguel, Edward, Shanker Satyanath, and Ernest Sergenti. 2004. Economic shocks and civil conflict: An instrumental variables approach. *Journal of Political Economy* 112(4):725–753.

Nogales, Alberto, Rodrigo Archondo-Callao, and Anil Bhandari. 2002. *Road Cost Knowledge System*. Washington, DC: World Bank.

Northrup, David. 1978. *Trade Without Rulers: Pre-Colonial Economic Development in South-Eastern Nigeria*. Oxford, UK: Claredon Press.

Nunn, Nathan. 2008. The long term effects of Africa's slave trades. *Quarterly Journal of Economics* 123(1):139–176.

Nunn, Nathan and Leonard Wantchekon. 2008. The slave trade and the origins of mistrust in Africa. Processed, Harvard University.

Oak Ridge National Laboratory. 2001. *LandScan Global Population Database 2000*. Oak Ridge, TN: Oak Ridge National Laboratory.

Olken, Benjamin A. 2006. Do television and radio destroy social capital? Evidence from Indonesian villages. Processed, Harvard University.

Podlewski, André Michel. 1961. Etude démographique de trois ethnies païennes du Nord-Cameroun: Matakam, Kapsiki, Goudé. *Recherches et Etudes Camerounaises* 4:1–70.

Ramcharan, Rodney. 2006. Does economic diversification lead to financial development? Evidence from topography. Working Paper 06/35, International Monetary Fund.

Rapaport, Eric and Folke Snickars. 1999. GIS-based road location in Sweden: A case study to minimize environmental damage, building costs and travel time. In John Stillwell, Stan Geertman, and Stan Openshaw (eds.) *Geographical Information and Planning*. New York, NY: Springer, 135–153.

Rappaport, Jordan and Jeffrey D. Sachs. 2003. The United States as a coastal nation. *Journal of Economic Growth* 8(1):5–46.

Riley, Shawn J., Stephen D. DeGloria, and Robert Elliot. 1999. A terrain ruggedness index that quantifies topographic heterogeneity. *Intermountain Journal of Sciences* 5(1–4):23–27.

Robinson, James A., Ragnar Torvik, and Thierry Verdier. 2006. Political foundations of the resource curse. *Journal of Development Economics* 79(2):447–468.

Sachs, Jeffrey. 2001. The geography of poverty and wealth. *Scientific American* March:70–75.

Sachs, Jeffrey. 2005. *The End of Poverty*. New York, NY: Penguin Press.

Sachs, Jeffrey and Pia Malaney. 2002. The economic and social burden of malaria. *Nature* 415(6872):680–685.

Sachs, Jeffrey D. and Andrew M. Warner. 2001. The curse of natural resources. *European Economic Review* 45(4–6):827–838.

Sokoloff, Kenneth L. and Stanley L. Engerman. 2000. History lessons: Institutions, factor endowments, and paths of development in the New world. *Journal of Economic Perspectives* 14(3):217–232.

Teorell, Jan and Axel Hadenius. 2007. Determinants of democratization: Taking stock of the large-N evidence. In Dirk Berg-Schlosser (ed.) *Democratization: The State of the Art*. Opladen: Barbara Budrich Publishers, 69–95.

United Nations. 2007. *United Nations Common Database*. New York, NY: United Nations Statistics Division.

US Bureau of Mines. 1960–1996. *Minerals Yearbook*. Washington, DC: United States Government Printing Office.

US Geological Survey. 1996. GTOPO30. Sioux Falls, SD: United States Geological Survey Center for Earth Resources Observation and Science (EROS).

US Geological Survey. 1997–2007. *Minerals Yearbook*. Washington, DC: United States Government Printing Office.

US National Imagery and Mapping Agency. 2000. *Vector Map (VMAP) Level 0/Digital Chart of the World*. Fifth edition. Fairfax, VA: United States National Imagery and Mapping Agency.

World Bank. 2006. *World Development Indicators*. Washington, DC: World Bank.

Data appendix

Country boundaries

We assign geographic features to countries using digital boundary data based on the fifth edition of the *Digital Chart of the World* (US National Imagery and Mapping Agency, 2000), which we have updated to reflect 2000 country boundaries using information from the International Organization for Standardization ISO 3166 Maintenance Agency and other sources. We exclude areas covered by inland water area features contained in the same edition of the *Digital Chart of the World*. When calculating the percentage of each country's land surface area with certain characteristics or the average value of a variable for a country, we perform all calculations on a 30 arc-second geographic grid, correcting for the fact that the actual land area covered by a 30 arc-second cell varies with latitude.

Land area

The land area data are from the Food and Agriculture Organization (2008), except for Macau and Hong Kong where it is taken from the Encyclopædia Britannica.

Income per person

We measure average country-level income by the natural logarithm of real gross domestic product per person in 2000. The data are from the World Bank *World Development Indicators* (World Bank, 2006). Units are 2006 international dollars, with purchasing power parity conversions performed using the Elteto-Koves-Szulc method.

To check the robustness of our results to the use of income data from other time periods and from an alternative source, in table 2 we use the natural logarithm of real gross domestic product per person in 1950 and in 2000, and its annual average from 1950–2000, with data from Angus Maddison (Maddison, 2007, updated October 2008). Units are 1990 international dollars, with purchasing power parity conversions performed using the Geary-Khamis method.

Gem-quality diamond extraction

Data on carats of gem-quality diamond extracted by each country between 1958–2000 are obtained from the 1959–2004 editions of the *Mineral Yearbook*, published first by the US Bureau of Mines (US Bureau of Mines, 1960–1996) and then by the US Geological Survey (US Geological Survey, 1997–2007). We use the most recent data for each country-year in Volume I (Metals and Minerals), completed with data from Volume III (Area Reports: International) of the 1997–2000 editions. For countries that have split or changed boundaries, we assign diamond extraction on the basis of mine location with respect to current boundaries. The variable is then normalized by land area to obtain carats of gem-quality diamond per square kilometre.

Percentage of each country with fertile soil

On the basis of the FAO/UNESCO Digital Soil Map of the World and linked soil association composition table and climatic data compiled by the Climate Research Unit of the University of East Anglia, Fischer, van Velthuizen, Shah, and Nachtergaele (2002) identify whether each cell on a 5-minute grid covering almost the entire land area of the Earth is subject to various constraints for growing rain-fed crops. Based on plates 20 (soil moisture storage capacity constraints), 21 (soil depth constraints), 22 (soil fertility constraint), 23 (soil drainage constraints), 24 (soil texture constraints), and 25 (soil chemical constraints) in Fischer *et al.* (2002) and the country boundaries described above, we calculate the percentage of the land surface area of each country that has fertile soil (defined as soil that is not subject to severe constraints for growing rain-fed crops in terms of either soil fertility, depth, chemical and drainage properties, or moisture storage capacity). Cape Verde, French Polynesia, Mauritius and Seychelles are not covered by the Fischer *et al.* (2002) data, so for these countries we use instead the percentage of their land surface area that is classified by the Food and Agriculture Organization (2008) as arable land or permanent crop land.

Percentage of each country with tropical climate

Using detailed temperature and precipitation data from the Climatic Research Unit of the University of East Anglia and the Global Precipitation Climatology Centre of the German Weather Service, Kottek, Grieser, Beck, Rudolf, and Rubel (2006) classify each cell on a 30 arc-minute grid covering the entire land area of the Earth into one of 31 climates in the widely-used Köppen-Geiger climate classification. Based on these data and the country boundaries described above, we calculate the percentage of the land surface area of each country that has any of the four Köppen-Geiger tropical climates.

Average distance to the nearest ice-free coast

To calculate the average distance to the closest ice-free coast in each country, we first compute the distance to the nearest ice-free coast for every point in the country in equi-rectangular projection with standard parallels at 30 degrees, on the basis of sea and sea ice area features contained in the fifth edition of the *Digital Chart of the World* (US National Imagery and Mapping Agency, 2000) and the country boundaries described above. We then average this distance across all land in each country not covered by inland water features. Units are thousands of kilometres.

European colonial origin indicators

European colonial origin indicators are based on Teorell and Hadenius (2007). They distinguish between British, French, Portuguese, Spanish, and other European (Dutch, Belgian and Italian) colonial origin for countries colonized since 1700. For countries under several colonial powers, the last one is counted provided that it lasted for 10 years or longer. Since Teorell and Hadenius (2007) exclude the British settler colonies (the United States, Canada, Australia, Israel and New Zealand), we code theses as having a British colonial origin. We complete their data using the same rule to determine the European colonial origin of French Polynesia (French), Hong Kong (British), Macau (Portuguese), New Caledonia (French), Nauru (British), Philippines (Spanish), Puerto Rico (Spanish), and Papua New Guinea (British).

Legal origin indicators

Legal origin indicators (common law, French civil law, German civil law, Scandinavian law, and Socialist law) are from La Porta, Lopez-de-Silanes, Shleifer, and Vishny (1999). Some of our regressions include French Polynesia, absent from their data, which we have coded as French civil law.

African region indicators

Region indicators for Sub-Saharan Africa (East Africa, Central Africa, West Africa, and South Africa) are from Bratton and van de Walle (1997). We assign African countries North of the Saharan desert, which were not classified by Bratton and van de Walle (1997), to the region of North Africa.

Slave exports

Estimates of the number of slaves exported between 1400 and 1900 in Africa's four slave trades are from Nunn (2008). The data are constructed by combining shipping data with data from various historic documents reporting the ethnicities of slaves shipped from Africa. Combining the two sources, Nunn is able to construct an estimate of the number of slaves shipped from each country in Africa between 1400 and 1900 during Africa's four slave trades. We normalize the export figures by a country's land surface area, computed as explained above. Because some country's have zero slave exports, we take the natural logarithm of one plus the number of slaves exported per

Table 8: Basic summary statistics, inside and outside of Africa

	Mean	Standard deviation	Minimum	Maximum	Corr. with ruggedness
			Within Africa		
Ruggedness	1.110	1.279	0.115	6.202	
Log real GDP per person 2000	7.487	0.935	6.146	9.796	0.261*
Diamonds	21.224	63.875	0	368.230	-0.118
% Fertile Soil	31.660	21.318	0	81.699	0.098
% Tropical Climate	52.098	42.985	0	100	-0.203**
Distance Coast	0.430	0.357	0.000	1.254	-0.308
Slave export intensity	4.095	3.165	0	8.868	-0.538***
			Outside Africa		
Ruggedness	1.424	1.113	0.003	5.301	
Log real GDP per person 2000	8.934	0.979	6.666	10.965	-0.231**
Diamonds	0.502	3.382	0	34.385	-0.139
% Fertile soil	42.767	26.527	0	100	0.040
% Tropical climate	35.862	45.601	0	100	-0.150
Distance to coast	0.273	0.433	0.000	2.206	0.040

Notes: The table reports summary statistics, inside and outside of Africa, for our ruggedness measure and for our core set of control variables. The table also reports pair-wise correlation coefficients between ruggedness and each control variable. For these, ***, **, and * indicate significance at the 1, 5, and 10 percent levels. In the sample, the number of African countries is 49, and the number of non-African countries is 121.

thousand square kilometres. See Nunn (2008) for more information on the nature of the data, including why it is appropriate to use the natural logarithm of slave exports.

Quality of governance

To measure the quality of governance in each country, we use the composite variable "rule of law" from version VII of the World Bank's *Worldwide Governance Indicators* database (Kaufmann *et al.*, 2008). It consists of "perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence" (Kaufmann *et al.*, 2008, p. 7).

Distance to export markets

Four variables measuring the distance from each country to the closest slave market in each of Africa's four slave trades are taken from Nunn (2008). For the trans-Atlantic and Indian Ocean slave trades, the measure is the sailing distance from the point on the coast that is closest to the country's centroid to the closest slave market for that slave trade. For the trans-Saharan and Red Sea slave trades, the measure is the great-circle overland distance from the country's centroid to the closest slave market for that slave trade. Units are thousands of kilometres.

Population density in 1400

The data are constructed using historic population estimates from McEvedy and Jones (1978). For countries grouped with others in McEvedy and Jones (1978), we allocate population to countries in the group according to the distribution of population in 1950, obtained from United Nations (2007). We normalize total population in 1400 by the land area of each country, calculated as described above. Because the variable is extremely skewed to the left and because the territory covered by some countries today had zero population density in 1400, we take the natural logarithm of one plus population density (measured in people per square kilometre).