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SPATIAL PATTERNS OF DEVELOPMENT: A MESO APPROACH

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ABSTRACT

Over the last two decades, the literature on comparative development has moved from country-level to within-country analyses. The questions asked have expanded, as economists have used satellite images of light density at night and other big spatial data to proxy for development at the desired level. The focus has also shifted from uncovering correlations to identifying causal relations, using elaborate econometric techniques including spatial regression discontinuity designs. In this survey we show how the combination of geographic information systems with insights from disciplines ranging from the earth sciences to linguistics and history has transformed the research landscape on the roots of the spatial patterns of development. We discuss the limitations of the luminosity data and associated econometric techniques and conclude by offering some thoughts on future research.

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1 Introduction

In the early 1990s, the field of economic growth underwent a renaissance with the development of new theoretical insights[1] and major empirical advances examining a myriad of cross-country growth correlates (see Barro (1998) for an overview of the growth regressions). The increasing availability of internationally comparable data on output, its components, and prices (the Penn World Table (PWT) Project) allowed meaningful comparisons across a large number of countries and enabled the testing of competing theories of growth.[2]

From the cross-country growth regressions to the development accounting exercises, a series of influential empirical papers set the stage for a vibrant literature that explored the (conditional) correlates of economic growth across countries since World War II.[3] Emerging empirical regularities on the correlates of development and growth regarding the role of physical capital, human capital, financial development, geography, social characteristics, and institutions fueled theoretical work feeding back to further empirical investigations. This lively empirical literature, however, eventually faced increasing difficulties. The reasons were multifaceted, ranging from the econometric problems that plague small-sample estimations including coefficient instability stemming from multicollinearity, limited degrees of freedom, classical measurement error, outliers, and the sizable variation in the data quality and availability across countries (leading to nonclassical error in variables). In spite of running millions of regressions (Sala-i-Martin, Doppelhofer, and Miller (2004)), it became hard to even spot the robust correlates (Ciccone and Jarocinski (2010), Johnson, Larson, Papageorgiou, and Subramanian (2013)). Moreover, identification remained a perennial issue notwithstanding novel attempts to leverage aspects of a country's colonial history as a source of variation (La Porta, Lopez-de-Silanes, Shleifer, and Vishny (1998), Hall and Jones (1999), and Acemoglu, Johnson, and Robinson (2001)).

In the meantime, starting in the early 2000s the micro-development literature embraced in earnest randomization techniques, raising the bar for identification (Duflo, Glennerster, and Kremer (2006)). The yawning gap between the well-identified but (initially) limited in scope studies of micro development and the generalizable but less-credible lessons from the cross-country empirics proved a fertile ground for the development of a literature exploring within-country large-scale variation. This *meso* approach, while not problem free, attempts

[1] See, among others, Lucas (1988), Romer (1990), Azariadis and Drazen (1990), Grossman and Helpman (1991), Aghion and Howitt (1992), Galor and Zeira (1993), and Banerje and Newman (1993).

[2] For the history of the Penn World Tables and the International Comparison Project, see Heston and Summers (1996), Heston, Summers, and Aten (2011), and Feenstra, Inklaar, and Timmer (2015). Robert Barro and Jong-Wha Lee's laborious compilation of cross-country data on educational attainment and schooling since 1960 was also instrumental in estimating the role of human capital (Barro and Lee (2013)).

[3] See Barro (1991), Levine and Renelt (1992), Mauro (1995), Easterly and Levine (1997), and Klenow and Rodríguez-Clare (1997), among others.

to strike a delicate balance between the merits and drawbacks of both the macro and micro studies. The hallmark of this approach is that it draws on the empirical toolset of applied micro to shed light on broad macro questions, using large, often global, samples. By moving the analysis within countries, the economics research on the causes of (under)development has greatly benefited by incorporating insights from anthropology, political science, ethnology, and history. This new literature emerged thanks to the integration of geographic information systems (GIS) in the arsenal of development and growth economists. The growing availability of big spatial data, such as satellite imagery of light density at night, and the increasing willingness to leverage unconventional (from an economic point of view) data sources and contexts such as historical natural experiments, have greatly expanded the scope of questions tackled. Thanks to these developments, a new era for economic history and for the research on the deep roots of comparative development has dawned (see Diamond and Robinson (2010), Nunn (2014), and Margo (2017)).

Structure In this paper we discuss how images of satellite light density have proven to be a versatile proxy of spatial development, fostering empirical research in growth that takes a meso approach. In the next section we present the luminosity data, discuss works showing their connection with various proxies of economic well-being, and review their strengths and weaknesses. In Section 3 we discuss how luminosity has been combined with data on geography, ecology, history, and institutions at various levels of spatial aggregation to explore some of the fundamental inquiries in the fields of economic growth and development. We pay particular attention to studies focusing on borders and comment on the use of spatial regression discontinuity techniques. In the last section, we offer some thoughts on future research.

2 Development Seen from Outer Space

2.1 Pitfalls of Cross-Country GDP Estimates

In the last few years, growth economists have come to realize that even small revisions of GDP estimates lead to substantial variability, which matters crucially for the stability of the cross-country growth patterns. This nonrobustness of the cross-country growth determinants is quite problematic. The World Bank (WB), cognizant of this reality, has been spending significant resources in an attempt to shore up the ailing statistical agencies across the developing world (Jerven (2013)). For example, between 2005 and 2015, hundreds of millions of dollars have been allocated for this purpose to countries such as the Democratic Republic of Congo (DRC),

Bolivia, Mongolia, Indonesia, Nigeria, Ghana, and Afghanistan.[4]

Despite ongoing improvements in statistical capabilities across countries, problems remain, especially in low-income states that often lack functioning statistical systems. In Somalia and the DRC, for example, the last population census was carried out in 1975 and 1981, respectively. Measurement challenges are present even outside war-prone regions. The PWT, for instance, reports two sets of GDP estimates from China. In April 2014, Nigeria's GDP almost doubled overnight after a major revision. The large size of the underground economy and the high share of subsistence agriculture in many low-income and lower middle-income countries make it challenging to properly measure output (La Porta and Shleifer (2008)). Since measurement error is related to low state capacity, conflict, and industrial specialization, it is most likely nonclassical, making inference challenging. In fact, using data on the individual components of statistical capacity constructed by the WB in 2016, one can show that poorer countries are systematically less likely to follow international standards both in the quality of the underlying data sources as well as in the methodology employed in the construction of statistics. And the emergence of the new economy, with the growing importance of outsourcing and the fragmentation of production lines, further exacerbates issues.

This state of affairs has significantly impeded our progress in understanding the sources of the considerable variation in economic performance within and across societies around the globe. Then remote sensing scientists came to the rescue.

2.2 Luminosity Data

In the early 1990s, as the field of economic growth was booming, Woodruff Sullivan, an astronomer from the University of Colorado Boulder, pieced together a mosaic of about 40 individual satellite images of nighttime photographs (copies of film strips from the Defense Meteorological Satellite Program (DMSP) archives over the period 1974-1984), producing for the first time a global map of luminosity. Sullivan (1991) was struck by how clearly human activities such as street lighting, rangeland burning, slash-and-burn agriculture, natural gas burn offs in oil fields, and squid-fishing lights were reflected on the images. He was particularly surprised by how well certain political boundaries could be discerned; there were sharp spatial discontinuities in luminosity at the border between East and West Germany and between North and South Korea. While Sullivan foresaw that such information would be useful for economists in

[4]For example, the WB has allocated the following resources: $45 million to the DRC for the Statistics Development Program, $47 million to Indonesia for the Statistical Capacity Building-Change and Reform for the Development of Statistics (STATCAP-CERDAS), $10 million to Nigeria for the Statistics Development Program (NSDP), $2 million for Strengthening the National Statistical System of Mongolia, and $40 million for the Statistics Development Program of Ghana. Another $40 million has been invested in AFGHANSTAT: Strengthening the National Statistical System, and $83.3 million for Strengthening Statistical Capacity in Bolivia.

their quest to trace economic activity (echoing Croft (1978)), in his concluding remarks at the International Astronomical Union Colloquium, he lamented that "*the light pollution in urban centers both devastates astronomical observations and removes much of human kind from any familiarity with the night sky.*" Despite Sullivan's grim assessment, luminosity images would revolutionize the field of comparative development in the subsequent decades.

2.2.1 Properties

The United States Air Force Space Command manages the DMSP, which in turn monitors meteorological, oceanographic, and solar-terrestrial physics for the United States Department of Defense. For more than 40 years, the primary function of its orbiting satellites has been to record the weather via the daytime records of the Operational Line Scan (OLS) sensors. The OLS is an oscillating scan radiometer that generates images with a swath width of about $3,000$ kilometers, generating global coverage every 24 hours. The electromagnetic energy captured by the sensors during the night is mostly a product of human-related light-emitting activities. The DMSP-OLS images are processed at the National Oceanic and Atmospheric Administration's (NOAA) National Geophysical Data Center (NGDC), producing a six-bit number calculated for 30 arc-sec or 0.86 square kilometer cells at the equator. The intensity of lights is coded in a grid format ranging between 0 (no light) to 63. Although nighttime lights data have been gathered from satellites for more than four decades, the publicly available annual series begin in 1992 (data on earlier years were deleted because of space considerations).

The three annual datasets that NOAA has made publicly available are time-stable lights, unfiltered lights, and radiance-calibrated lights, respectively.

- The time-stable lights are created by overlaying all images captured during a calendar year, dropping observations of the moonlit half of the lunar cycle, pixels where the sun sets late in the summer, locations where the visibility of lights is hindered by clouds (a rather common phenomenon for cells closer to the tropics) or overpowered by the aurora or solar glare (near the poles), and removing ephemeral lights such as fire and lightning.

- The unfiltered lights are available for the same period and can potentially give more values at low luminosity, which is helpful for studies in areas with low levels of development, but it is often hard to distinguish it from the natural illumination of the soil.

- Radiance-calibrated lights give more variation at high luminosity levels, as they are not top coded. The latter is the process of censoring all values above a certain threshold.

Figure 1 illustrates the time-stable luminosity images recorded by the DMSP-OLS in 2013, the latest year available on a global scale.

Figure 1

2.2.2 Cross-Country Correlations

The satellite lights data considered as a proxy of economic activity have several attractive features. First, the recorded information is "objectively"measured, in the sense that it does not reflect any biases from the statistical agencies. Second, the data are available for all parts of the globe, except for the high and low latitudes (close to the Arctic and Antarctica). Third, as the satellites and their sensors improve, the data capture an increasing portion of economic activity.

The literature has applied various transformations of the underlying pixel data to aggregate luminosity in a given location. These include the sum of total night light in a given region, province, or country, the share of lit pixels, the average night light, and the log of average night light, either per square kilometer or per capita (sometimes a small number is added before taking the log to account for the presence of zeros). Many high-resolution studies also employ a binary, 0-1, transformation that accounts for the highly nonlinear nature of the data. Building on Elvidge, Baugh, Kihn, Kroehl, and Davis (1997) and Doll, Muller, and Morley (2006), Henderson, Storeygard, and Weil (2012) introduced the luminosity data to economics, showing that light density at night is a robust proxy of economic activity across and within countries (see also Pinkovskiy (2017)). Although some debate whether the association between light density and incomes per capita is stronger for levels rather than growth rates, it is clear that luminosity can be a powerful proxy of economic activity for regional analyses in war-prone countries and those with poor-quality national statistics. These are precisely the regions where understanding the causes of underdevelopment is likely to be of greater value

added (see Chen and Nordhaus (2011), Henderson, Storeygard, and Weil (2012), and Chen and Nordhaus (2014)).

Figure 2 depicts the cross-country relationship between log average luminosity per square kilometer in 2000 and log GDP per capita in 2000, partialling out continental fixed effects. There is a strong correlation that is also present within each continent separately (results not shown).

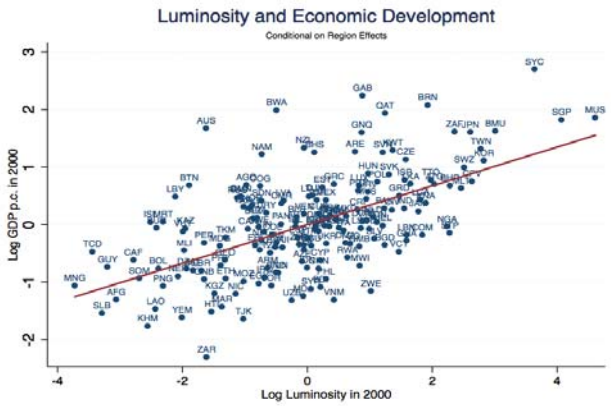

Figure 2

Henderson, Storeygard, and Weil (2012) show that a similarly strong correlation emerges when one estimates the association between luminosity and GDP in log differences over the period 1992-1993 to 2005-2006 across 170 countries, finding an elasticity of 0.32 and an R^2 of around 0.28. Figures $3a - 3b$ illustrate the usefulness of luminosity as a proxy of economic development over the medium run, focusing on South Africa in 1994 and 2012. In line with GDP statistics and anecdotal evidence of robust growth in South Africa since the fall of apartheid, luminosity has increased considerably.

Figure 3*a*

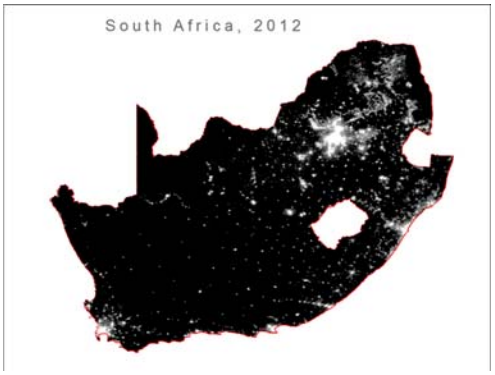

Figure 3*b*

Starting from the observation that while both luminosity and GDP series are noisy proxies of the true underlying output, their respective error structures are likely to be uncorrelated.

Henderson, Storeygard, and Weil (2012) use standard statistical aggregation techniques to combine the GDP and lights series to construct an updated output series. Their analysis shows that in many countries (e.g., Burundi, Haiti, Ivory Coast and the Congos), actual GDP statistics understate growth over the period 1993-2006, whereas in others (e.g., Angola, Myanmar, Vietnam, and Ghana), GDP estimates tend to overstate real output growth.[5] A work similar in spirit is that of Pinkovskiy and Sala-i-Martin (2016a), who use luminosity as an auxiliary variable to help uncover the correlation structure between GDP per capita and consumption and income surveys. They construct revised data on poverty rates across countries, finding that global poverty has been falling considerably in most parts of the world, including Africa (see also Pinkovskiy and Sala-i-Martin (2016a)).

2.2.3 Within-Country Regional Correlations

The main advantage of the luminosity data is that, thanks to its fine resolution, it permits comparisons of economic activity across regions in the same country. Hence, a natural question is whether luminosity reflects local development, for example, across states/provinces/regions, administrative units, or other spatial partitions. There are considerable econometric benefits of conducting within-country empirical analyses, since one can account for nationwide features that are common to all regions including national policies, history and institutions, and even measurement error (which quite often has a sizable country-specific component).

Global Hodler and Raschky (2014) show that log luminosity and log output are related at the regional level. Similarly, Gennaioli, La Porta, Lopez-de-Silanes, and Shleifer (2013) in a sample of $1,503$ regions across 83 countries, estimate the elasticity to be around 0.25, only slightly smaller than the cross-country elasticity reported by Henderson, Storeygard, and Weil (2012). They further show that nonlinearities at this level of spatial aggregation are small and not important quantitatively.

Africa In Michalopoulos and Papaioannou (2013) we present graphical illustrations of significant regional correlation between luminosity and survey-based measures of well-being using data from the Demographic and Health Surveys (DHS) from 4 African countries (Zimbabwe, Tanzania, Nigeria, and the DRC). In Figure 4*a* we plot the correlation between log luminosity and the DHS composite wealth index across admin-3 level units, netting out country-survey fixed effects (see Chiovelli, Michalopoulos, and Papaioannou (2017)). The data are retrieved

[5] In recent work Pinkovskiy and Sala-i-Martin (2016b) use luminosity data to evaluate the accuracy of the various vintages of the Penn World Tables, using again the insight that noise in GDP statistics is unlikely to be correlated with measurement error in satellite imagery data. Their analysis shows that newer vintages of the Penn World Table are more, rather than less, noisy proxies of the underlying economic activity.

from 74 DHS surveys that cover close to 9,000 third-level administrative units from 21 African countries. The coefficient on log luminosity is 0.3 and highly significant, and the within R^2 is 0.30-0.37. Figure 4*b* shows that regional luminosity also correlates with average years of schooling at the district level. The patterns are similar at the admin-2 level.

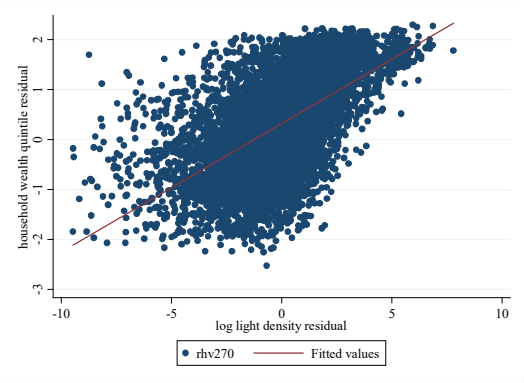

Figure 4*a*

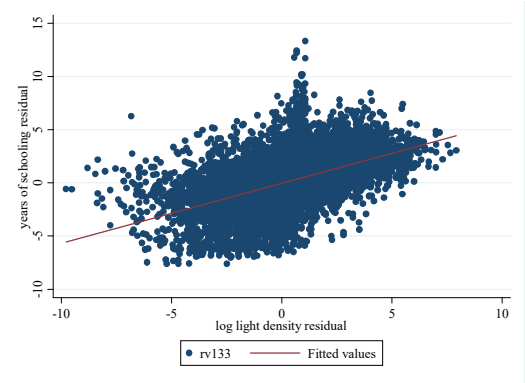

Figure 4*b*

But what about rural areas in low-income countries where luminosity is either zero or very small? Can luminosity be used to proxy economic activity in such places as well? Figure 5 shows that in administrative regions where the satellites detect some light, wealth and mean education are considerably higher, as compared to regions that do not emit any light. This pattern is present in both urban and rural areas in Africa, suggesting that while nonlinearities may be present, luminosity can be used to proxy for development even in low-income rural areas with low population density. A similar pattern emerges when we associate luminosity with mean education.

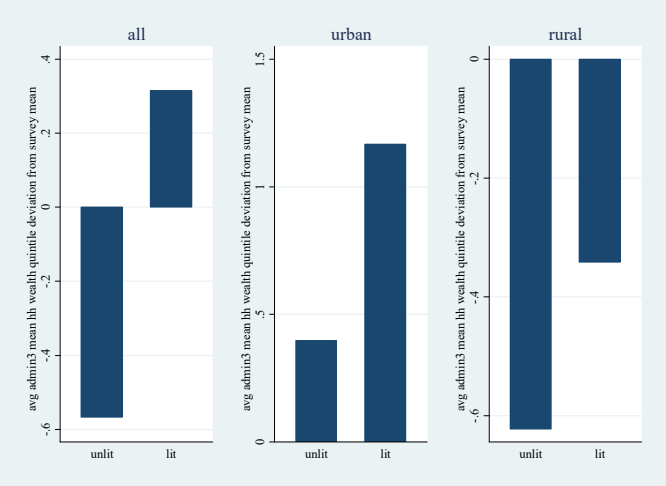

Figure 5

Weidmann and Schutte (2017) report similarly strong correlations between luminosity and the DHS composite wealth index across regions and even neighborhoods using data covering 39 low-income, mostly nondemocratic countries. Bruederle and Hodler (2017) show that luminosity also correlates with education, health, and public goods across DHS enumeration areas in Africa.

Latin America Looking within Brazil is useful because its statistical agency reports output estimates for close to $3,500$ municipalities during the period 2000-2011. There is an evident unconditional association between log municipal income, as given by census data in 2000 and 2010, with log luminosity (Figure 6*a*) that retains significance once we partial out year and state fixed effects to account for the sizable differences between the North and the South (Figure 6*b*). The highly significant elasticity is 0.30, and the in-sample fit is good with an R^2 of 0.25.

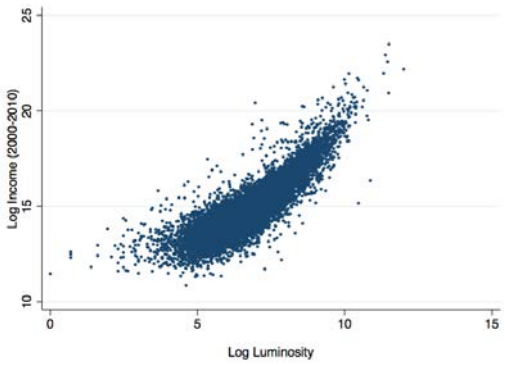

Figure 6*a*

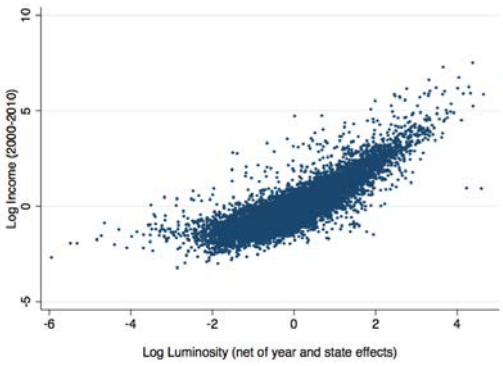

Figure 6*b*

Other Even for developed countries like Sweden with reliable national statistics, it nevertheless turns out that nighttime lights are strong predictors of *aggregate* local economic activity, reflected in establishment and population density, though uncorrelated with average wages (Mellander, Lobo, Stolarick, and Matheson (2015)). This suggests that researchers using nighttime lights may want to discuss whether their proxy of development is a better measure of urbanization/agglomeration and aggregate economic activity or also potentially reflects differences in the per capita standards of living. In the case of developing countries, urbanization and per capita incomes are often strongly correlated, whereas for the developed world, this relationship may be more nuanced.

A potential avenue to assess whether differences in luminosity also reflect per capita differences in income is to adjust the luminosity measures using the available gridded population

datasets.[6] However, using luminosity per capita may lead to hard-to-sign biases, due to non-linearities in the luminosity-population elasticity, noise in local population estimates (which surely differs across countries), and the logarithmic transformation. Thus, may be preferable to use (log) average luminosity per area and directly control for (log) population density on the right-hand side. By doing so, there is no a priori restriction, and one can also easily explore potential non linearities. Researchers may also compare estimates with (log) average luminosity as the outcome to similar regressions using (log) population density.

2.2.4 Caveats and New Satellite Sensors

DMSP-OLS luminosity statistics are not problem free. Donaldson and Storeygard (2016) provide an excellent review on the history, benefits, and caveats of satellite images and the use of remote sensing more generally. So, here we briefly touch on the core issues.

First, as satellite sensors age and new satellites are launched, the comparability of luminosity across time, both within as well as across satellites, is not straightforward. Hsu, Baugh, Ghosh, Zhizhin, and Elvidge (2015) improve on this issue by providing appropriate adjustment parameters.[7]

Second, luminosity data are subject to saturation, which results in top-coded values. Although such instances are less pressing for large swaths of the developing world, usually in the handful of megacities,[8] saturation is a more common phenomenon for the urban core of developed countries. The availability of radiance-calibrated lights addresses this issue by providing non-top-censored imagery.

Third, the data are highly skewed. Many parts of the world appear "dark" where pixels emit just a bit of light and in the capitals of the rich countries luminosity takes extreme values. However, these issues can be addressed by either employing nonlinear (maximum likelihood) econometric techniques or transforming the data (takings logs, focusing on the extensive margin, etc.).

Fourth, luminosity images are subject to blooming; lights, especially bright lights, appear larger than they actually are over water- and snow-covered areas. For example, because of blooming light emitted by cities often falls outside the respective urban boundaries (Small, Pozzi, and Elvidge (2005)). This issue of spatial spillover of light becomes more pressing at high-resolution levels when one compares economic activity across contiguous small cells,

[6] Center for International Earth Science Information Network (CIESIN), Columbia University, and Centro Internacional de Agricultura Tropical (CIAT), 2005. Gridded Population of the World Version 3 (GPWv3): Population Density Grids. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University.

[7] In practice, this may not be a severe issue since the inclusion of time/year fixed effects also accounts in a nonparametric way for time trends related to sensor aging and replacements.

[8] For example, in Africa in 2007, out of the $30,457,572$ pixels of light density, only 0.00017% are top coded.

neighborhoods, and borders in general. Alexei, Lozano-Gracia, and Oram (2016) recognize that blurring occurs because of the DMSP satellites' onboard optics and construct an algorithm that corrects for this bias.

Fifth, the relatively coarse spatial resolution of satellite sensors, the limited dynamic range, and its six-bit quantification have been also considered as weaknesses of the DMSP-OLS sensor. Many of these limitations have been addressed by the latest generation of sensors known as VIIRS (visible infrared imaging radiometer suite). VIIRS is one of the five instruments aboard the Suomi-NPP satellite, which was launched in 2011. It is a scanning radiometer that collects visible and infrared imagery and radiometric measurements of the land, atmosphere, cryosphere, and oceans. VIIRS data are used to measure cloud and aerosol properties, ocean color, sea and land surface temperature, ice motion and temperature, fires, and the Earth's albedo (defined as the ratio of irradiance reflected to the irradiance received by a surface.).

A major improvement of VIIRS, compared to previous satellite imagery, is its high resolution. In the DMSP-OLS luminosity data, each cell's recorded light comes from a footprint of roughly 3-5 kilometers in diameter, so in practice all measurements are autocorrelated at that distance. In contrast, the VIIRS uses 64 detector aggregation zones to maintain a constant footprint of a diameter of 742 meters. Thus, the footprint of VIIRS is 45 times smaller than that of the DMSP, improving significantly on the spatial dependency issue (see Elvidge, Baugh, Zhizhin, and Hsu (2013)). Another difference is that the DMSP-OLS has a nighttime overpass roughly around 19:30 whereas VIIRS has an overpass around 1:30. This is why despite VIIRS's substantially lower detection limit than the OLS, the former images appear on average more dimly lit.[9] Li, Li, Xu, and Wu (2017) provide an algorithm that links VIIRS with DMSP. They first develop an adjustment procedure that transforms the two luminosity series in the same digital units. They then identify a nonlinear relationship that allows the transformation of the VIIRS numbers to the DMSP scale.

2.2.5 Spatial Aggregation and Patterns

Administrative Regions A straightforward benefit of the satellite imagery data on luminosity is that one can easily aggregate them and construct proxies of economic activity across administrative units. In an interesting application, Hodler and Raschky (2014) show that changes in countries' leadership are associated with increases in luminosity at the leader's birthplace. They further show that regional favoritism is especially strong in countries with weak constraints on the executive (where leaders have more discretion) and in countries with

[9] According to Elvidge, Baugh, Zhizhin, and Hsu (2013) the OLS detection limit is near 5E-10 watts/cm2/sr, whereas the corresponding number for VIIRS is 2E-11 watts/cm2/sr. The lower detection limits of VIIRS enables the detection of dimmer lighting.

low levels of education.

Another application is the one by Alesina, Michalopoulos, and Papaioannou (2016), who combine luminosity data with administrative (as well as ethnolinguistic) maps to construct cross-country measures of regional and ethnic inequality, bypassing data unavailability of regional incomes in the developing world. They then show that inequality across ethnic homelands and administrative regions is strongly related to underdevelopment.

Beyond Administrative Boundaries But a major benefit of the luminosity data is that researchers do not have to depend any more on official statistics available at predetermined administrative levels (often drawn based on local economic, political, and social considerations). This allows economists to view the same cell on Earth in a variety of different spatial contexts. One way to completely disassociate one's analysis from these politically chosen boundaries (and the process of country and administrative-region formation more generally), for example, is to partition countries or the world into virtual "boxes/countries"and use this as the primitive spatial unit. See Michalopoulos (2012) for an early application of this virtual-country approach. Figure 7 maps the deciles of average luminosity in 2013 across "boxes" of 4 by 4 decimal degrees.

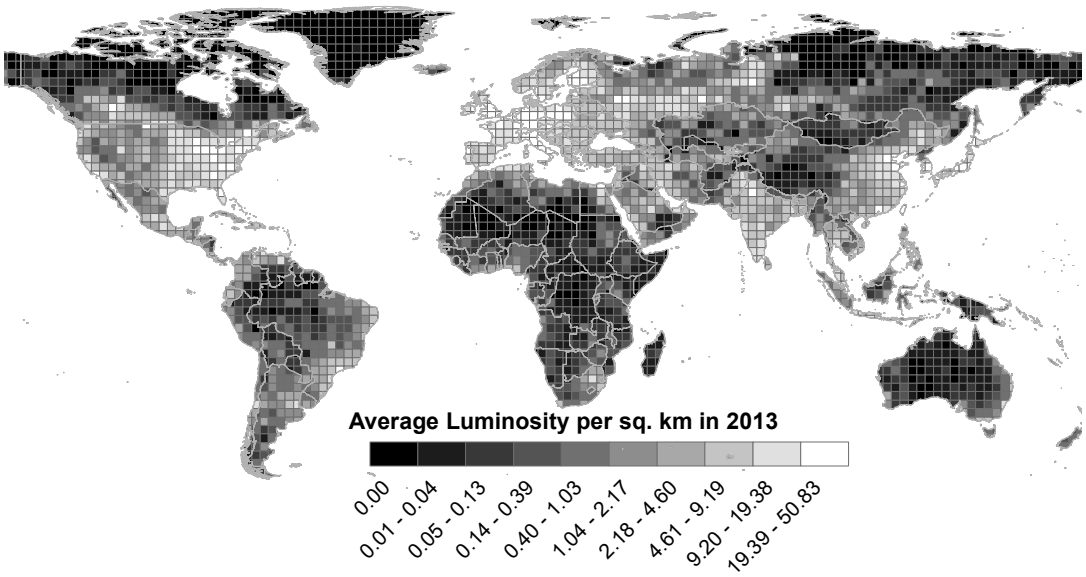

Figure 7

Ethnic, Linguistic, and Religious Boundaries Besides creating artificial units, the inquiry on the causes of spatial development has embraced the idea that ethnic and linguistic homelands, religious groups, and historical empires may be the relevant units for understanding variation in economic performance across space (Michalopoulos and Papaioannou (2013, 2014, 2016)). In fact, identifying the role of deeply rooted historical factors on comparative

development has been greatly aided by moving away from bureaucratically preordained units of analysis and measures of development (see Michalopoulos and Papaioannou (2017) for a compilation of related contributions over the last 20 years).

An interesting case, shown in Figure 8*a*, is Zomia, a mountainous region the size of Europe that spreads over seven Asian countries.[10] Should one wish to pay particular attention to the poorest countries in the region, namely, Cambodia, Myanmar, Laos, and Bhutan, without the use of geographic information systems, one's analysis would be severely limited. It would effectively imply relying on official statistics from Myanmar, which came out of five decades of military dictatorship just few years ago; or from Bhutan, whose head of state, King Jigme Singye Wangchuck, famously said in 1979, "We do not believe in Gross National Product. Gross National Happiness is more important"; or from Cambodia, a country where land mine contamination has rendered large areas inaccessible.

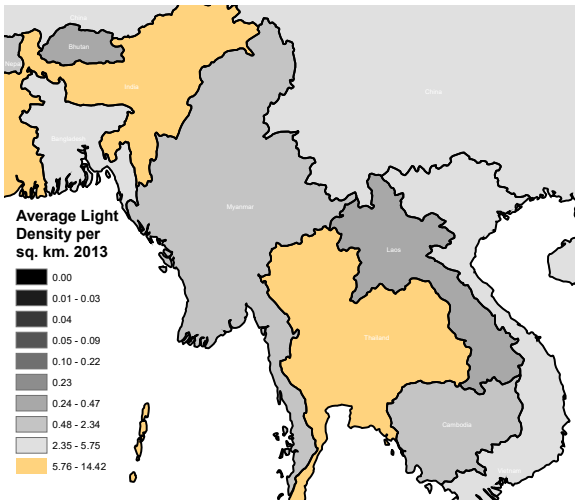

Figure 8*a*

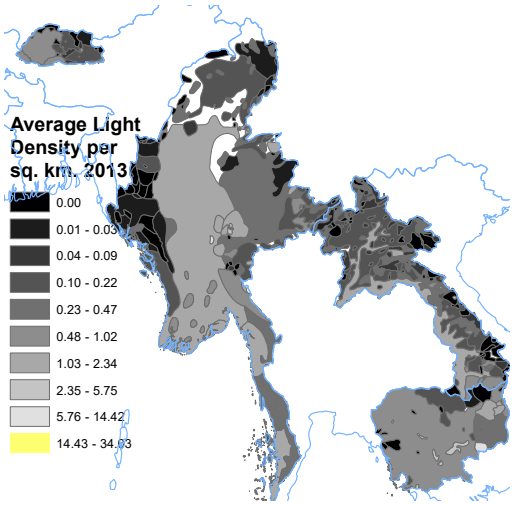

Figure 8*b*

[10] Zomia is a geographical term coined in 2002 by the historian Willem van Schendel to refer to the mass of Southeast Asia mainland that has historically been beyond the control of governments of the lowlands.

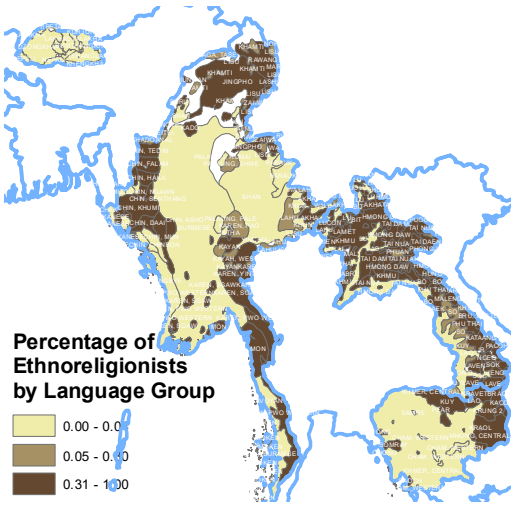

Figure 8*c*

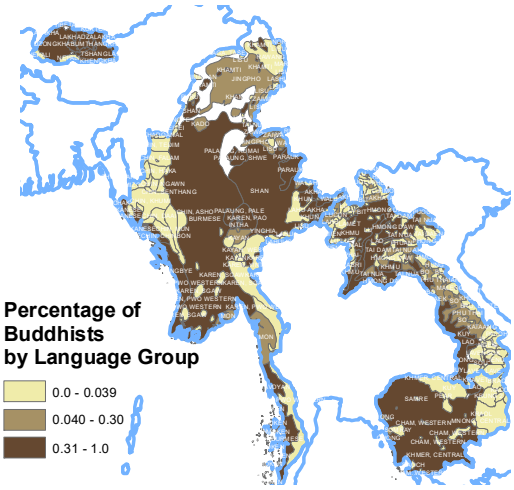

Figure 8*d*

James Scott's (2009) celebrated study of the Zomia highlands reveals the complexity of the ethnic landscape; people of various groups have historically fled their houses in response to nation-building projects from the surrounding societies and have designed their social organization, as well as chosen geographical location and subsistence practices and culture, to discourage states from annexing them into their territories. Hence, a more appropriate mapping of the underlying social landscape of this region would be the ethnic and linguistic homelands of these groups. Figure 8*b* depicts deciles of average luminosity per square kilometer in 2013 at the ethnolinguistic homeland level, as recorded in the 15th edition of the *Ethnologue* dataset (Gordon and Grimes (2005)).[11] There is considerable variation in light density across the 204 ethnolinguistic territories within Bhutan, Laos, and Myanmar. Figures 8*c* and 8*d* provide an alternative mapping of the Zomia highlands. Specifically, we map for each group the respective shares of Ethnoreligionists (Figure 8*c*) and Buddhists (Figure 8*d*), as recorded in the *World Christian Encyclopedia* (Barrett, Kurian, and Johnson (2001)). The clustering of religious identity and economic activity is evident with implications about the degree of ethnic and religious inequality.

The case of Zomia is telling of a wider phenomenon. Ethnographers, historians, and anthropologists have long pointed out that in large parts of the developing world where the state is weak, social and economic activity takes place within the confines of ethnic, linguistic or religious groups that are often characterized by a great deal of heterogeneity in their social, institutional, and economic structure. Synthesizing a large body of anthropological research,

[11] Each of these polygons delineates a traditional linguistic homeland; populations away from their homelands (e.g., in cities and refugee camps), linguistic groups of unknown location, widespread languages, and extinct languages are not mapped.

George Peter Murdock (1967) and subsequent authors have put together a comprehensive dataset on the cultural, political, and economic features of a large cross section of ethnic groups around the world. Using a plethora of sources, Murdock (1967) documents a wealth of characteristics mostly for groups in Africa, Asia, Oceania, and the New World, prior to contact with Europeans. The fruits of this major effort are recorded in the *Ethnographic Atlas* (EA) (published in 29 installments in the anthropological journal *Ethnology*), reflecting the cultural, geographical, and economic traits of 1,270 ethnicities.

The realization that the ethnic group is the relevant social unit has been particularly fruitful for understanding the origins of regional development in the context of Africa. In a series of papers (Michalopoulos and Papaioannou (2014, 2015, 2016)), we have combined luminosity data with Murdock's map depicting the spatial distribution of ethnicities in Africa on the eve of the colonial era (Murdock (1959)) and information from the EA to test various conjectures on the origins of comparative African development (Murdock (1967)).

2.3 Spatial Development around the World

Images such as the one depicted in Figure 1 immediately beget the question on the determinants of the location of economic activity. Recently scholars have combined the satellite imagery data on luminosity with fine-resolution images of geography and ecology-related traits. Examples of high-resolution GIS data include land quality for agriculture,[12] natural productivity of the ocean (Dalgaard, Knudsen, and Selaya (2016)), rainfall, ecological suitability for malaria (Kiszewski, Mellinger, Spielman, Malaney, Sachs, and Sachs (2004)), and terrain ruggedness and elevation. Geography has been linked to development at least since the time of Adam Smith and Montesquieu (or even Aristotle); and various, mostly cross-country works have shown that economic growth and output correlate with numerous geographic traits, such as malaria (Sachs (2005)), distance to the equator (Hall and Jones (1999) and Andersen, Dalgaard, and Selaya (2016)), isolation (Nunn and Puga (2012)), and proximity to the coast (Rappaport and Sachs (2003)), among many others. Recent works further uncover the indirect effects of geography on development and the social composition (e.g., Diamond (1997), Acemoglu, Johnson, and Robinson (2001), Michalopoulos (2012), and Michalopoulos, Naghavi, and Prarolo (2018)).

Henderson, Squires, Storeygard, and Weil (2017), motivated by the observation that in broad strokes economic activity in the United States is significantly more spatially concentrated compared to that in Europe, analyze whether geographical attributes may have a time-varying

[12] Crop-specific suitabilities have been widely used among agricultural economists and also recently by economists interested in within-country comparative development. The data come from FAO-IIASA's Global Agro-Ecological Zones (GAEZ) project from the Food and Agriculture Organization and the International Institute for Applied Systems Analysis. For an alternative mapping of a cell's agricultural potential based on caloric suitability, see Galor and Ozak (2015).

impact on the location of economic activity depending on how early a given location developed. In the first part of their study, they establish the powerful explanatory nature of geography in shaping economic activity. They find that a relatively small set of 24 geographical attributes explain 47% of the worldwide variation and 35% of the within-country variation in luminosity observed across 240,000 grid cells. In the second part, they show that agriculture-related geographic variables wield disproportionate explanatory power vis-a-vis trade-related geographic traits among early developers, and this pattern is balanced for late developers. The rationale they offer is the following. Among early developers, high transportation costs made it necessary for urban centers to remain close to the agricultural core persisting to today. On the contrary, among late developers the decline in the transportation costs facilitated the rise of cities close to trade-privileged coastal locations.[13]

3 Border Studies of Spatial Development

One of the advantages of moving the exploration of the roots of development within countries is that, partly thanks to overcoming the limited degrees of freedom, one may now exploit a wide range of identification strategies.[14] Naturally, randomization of historical events, social composition, or random assignment of any of the fundamental growth correlates for that matter is hard, if not impossible. Nevertheless, comparing economic activity across borders (national, subnational, ethnic, linguistic, of historical polities, colonial concessions, etc.,) has emerged as a focal identification strategy improving the credibility of the empirical estimates.

The research field of border studies has a veritable history and has attracted attention from a wide variety of disciplines including political science, sociology, anthropology, history, international law, and, more recently, even from the humanities — notably art, media studies, philosophy, and ethics. And since the seminal paper of McCallum (1995), who found that cross-province trade in Canada is 22 times more frequent than between provinces and US states, a large literature on the trade impediments associated with international borders has followed.

Social scientists have long been fascinated by frontier zones, producing a rich account of the historical, social, and institutional history of these regions (hence the stand-alone field of border studies). Getting a glimpse of economic activity of these places and its determinants was largely out of reach for development and growth economists, limiting the cross-pollination of economic reasoning from neighboring disciplines. In other words, before the integration of

[13] Recently, there has also been an increased interest in the role of infrastructure and trade costs on spatial development (often proxied by luminosity), which owing to space constraints we do not review here. See, among others, Eaton and Kortum (2002), Arkolakis, Costinot, and Rodríguez-Clare (2012), Jedwab and Storeygard (2016), Alder (2015), Donaldson and Hornbeck (2016), and Campante and Yanagizawa-Drott (2017).

[14] Fuchs-Schündeln and Hassan (2015) provide a thorough review of natural experiments in macroeconomics.

GIS in their empirical arsenal, economists could remain largely insulated from the nuances and specificities of spatial development, since the absence of credible proxies of local economic performance limited such empirical explorations on a large scale. This has changed dramatically over the last 10 years. Below we review some of these works by topics explored.

Linking the past of a given location to its current performance has benefited particularly from the utilization of spatial regression discontinuity designs, mostly because mapping the locations of historical events to modern-day territories is relatively easier than tracing the history of the lineage of a given individual. Looking at places, for example, on both sides of a historical boundary, we can compare contemporary outcomes and uncover the imprint of whatever it was that differed between the two regions historically. This strategy has been fruitfully applied in examining the role of institutions, which tend to have a territorial base.

3.1 Cross-Country Border Studies

Recent works associate national border differences in development, as reflected in luminosity, with differences in various country features (e.g., institutions, fragmentation, human capital). By typically employing regression discontinuity designs, these studies advance on causality.

In Michalopoulos and Papaioannou (2014), for example, we examine the role of national institutions in shaping regional development across African countries. We exploit the artificial drawing of colonial borders that endured after African independence and examine whether differences in regional development across the national border today are related to differences in national institutions. We conduct the analysis within the historical homelands of ethnic groups that have been systematically partitioned by the artificial colonial borders so as to account for unobserved ethnic and geographic features.[15] The analysis within ethnic homelands reveals no systematic link between national institutions (rule of law, bureaucratic quality, control of corruption) and luminosity. While the lack of any association goes against works stressing the causal impact of institutions on development, it is in line with the African historiography that stresses the role of ethnic rather than national features and emphasizes the inability of the central government to broadcast power far from the capitals (Herbst (2000)).[16] Consistent with this narrative, we show that various proxies of state capacity decline as one moves away

[15] In Michalopoulos and Papaioannou (2016) we assess the consequences of the colonial border design that resulted in the splitting of more than a quarter of the preexisting ethnic groups across the African countries upon decolonization. After showing that partitioned groups were similar in many respects to nonpartitioned ones, we establish empirically using high-precision georeferenced data on local events of political violence that partitioned ethnic homelands have suffered disproportionately from state-sponsored violence and discrimination, uncovering the violent legacy of the colonial border design.

[16] There is a plethora of case study evidence on the importance of ethnic institutions and leaders (e.g., Baldwin (2012)). Using data from the Afrobarometer Surveys, Logan (2009) and Michalopoulos and Papaioannou (2015) present descriptive evidence on the salience of ethnicity and the crucial role of ethnic chiefs.

from the capital cities. And there is a weak link between national-level institutional quality and within-ethnicities differences in economic activity, as reflected in the satellite images of light density at night, for those groups close to the capital cities.[17]

In a follow-up study, Pinkovskiy (2017) examines the patterns of luminosity across national borders globally. He first documents the presence of sizable border discontinuities in luminosity, suggesting the importance of nationwide differences. Second, he examines the role of human capital, infrastructure, institutions, and state capacity and finds that the overall level of national development and growth, and to a lesser extent of national institutions, explains differences in luminosity at the border. Third, there is substantial heterogeneity across continents, with national institutions playing a significant role in Europe and the Americas and having no explanatory power in Africa.

3.2 Within-Country Borders

Studies associating at-the-border differences in development (and other outcomes) with countrywide features are useful because they advance on identification; however, they are still subject to the critique that some other nationwide feature may explain these border differences. Economists have recently combined GIS data with historical maps to examine the importance of history, colonial institutions, and oppressive labor practices, exploiting within-country variation.

Colonial Concessions Assessing the developmental impact of colonization has been a fertile ground of research among growth and development economists (Acemoglu, Johnson, and Robinson (2005), La Porta, Lopez-de-Silanes, and Shleifer (2008)). The colonial heritage, however, is multifaceted and far-reaching, which makes sweeping mono-causal explanations difficult. Nevertheless, an aspect of the colonial era that has recently attracted attention is that of the legacy of colonial resource extraction. It is useful to remember that one of the key reasons behind the push toward colonization was the acquisition of natural resources and foodstuff that would ease the pressure of the growing population in the European homelands. The exploitation of the resources either was directly undertaken by the state, or chunks of land would be contracted out to private firms through the system of colonial concessions. This practice was widespread, with hundreds of concessions dotting the colonial landscape. Tracing the impact of such colonial exploitative practices has been greatly facilitated by the presence of relatively precise maps delineating the boundaries of public or private colonial exploitations.

[17] Dickens (2017) employs a similar identification strategy to explore the extent of ethnic politics across African groups over time.

Comparing villages and districts on two sides of a boundary can shed light on this important aspect of the colonial experience.

In an early study, Dell (2010) applied a regression discontinuity design to investigate the long-run impact of the *mita*, an extensive forced mining labor system affecting parts of Peru and Bolivia between 1573 and 1812. Proxying development with health and consumption survey data, Dell (2010) finds that *mita* regions are underperforming today compared to the neighboring non-*mita* districts and this difference is partially driven by the scarcity of large landowners and the abundance of subsistence farmers in the *mita* districts today.

Lowes and Montero (2015) look at another infamous instance of colonial exploitation throughout King Leopold II's Congo Free State (CFS). The CFS granted concessions to private companies that used violent tactics to collect rubber and other minerals. Using a regression discontinuity design along the well-defined boundaries of the two major concessions, the authors find that greater exposure to the rubber concessions is associated with lower education, wealth, and health outcomes today. They go a step further by using survey and experimental data from a former concession boundary to shed light on these channels, finding that village chiefs in former concessions are less likely to be elected and provide fewer public goods today.

Dell and Olken (2017) look at the consequences of the Dutch cultivation system in Java, showing that areas close to where the Dutch established sugar factories in the mid-19th century are more industrialized today, suggesting that the economic structures implemented by colonizers to facilitate production can continue to promote economic activity in the long run. This burgeoning literature is likely to enrich our understanding of the colonial legacies.

Precolonial Legacies in Africa In Michalopoulos and Papaioannou (2013) we combine luminosity data with Murdock's map depicting the spatial distribution of ethnicities in Africa on the eve of the colonial era (Murdock (1959)) and information from Murdock's atlas on various precolonial ethnic-specific institutional, social, and economic features to test various conjectures on the origins of comparative African development (Murdock (1967)).[18] We put to test a long-standing conjecture among African scholars regarding the legacy of deeply rooted ethnic institutions, in particular, the role of precolonial political centralization (see Herbst (2000)). The use of satellite imagery data is quite desirable, as it allows us to conduct the analysis across all of Africa. Figures 9*a*-*c* illustrate our approach. Figure 9*a* depicts stable nighttime luminosity at the cell level as of 2013, and Figure 9*b* aggregates the data at the

[18] Starting with Gennaioli and Rainer (2007) and Nunn (2008), many empirical papers have used Murdock's data and mapping of the spatial distribution of ethnicities. See Fenske (2013), Alesina, Brioschi, and La Ferrara (2016), Michalopoulos, Putterman, and Weil (2016), Nunn and Wantchekon (2011) , Giuliano and Nunn (2013), Fenske (2014), Alsan (2015), Mayshar, Moav, Neeman, and Pascali (2015), Osafo-Kwaako and Robinson (2013), Alesina, Giuliano, and Nunn (2013), and Bentzen, Hariri, and Robinson (2015).

country-ethnic homeland level, using Murdock's map and contemporary borders (as of 2000). In Figure 9*c* we map the degree of ethnic-specific political centralization at the time of the European colonization of Africa. This index describes the number of jurisdictional layers above the local (usually village) level for each group. A zero score indicates stateless societies lacking any form of centralized political organization. A score of 1 indicates small chiefdoms, 2 designates paramount (large) chiefdoms, and 3 and 4 indicate ethnic groups that were part of large states.

Our econometric analysis shows that within African countries, groups that were organized as large chiefdoms or states during the precolonial era (such as the Zulu and Tswana) are more developed today, as compared to ethnicities organized in small chiefdoms or those lacking any degree of political complexity (such as the Nuer or the Tiv). And while the precolonial political centralization - contemporary development nexus may reflect hard-to-account-for inertia or omitted factors, we show that the correlation between the two is present when we control for dozens of other precolonial societal, economic, and organizational features. We also compared development at the ethnic border of groups differing in their degree of precolonial political complexity. The RD estimates confirm the cross-sectional pattern.[19]

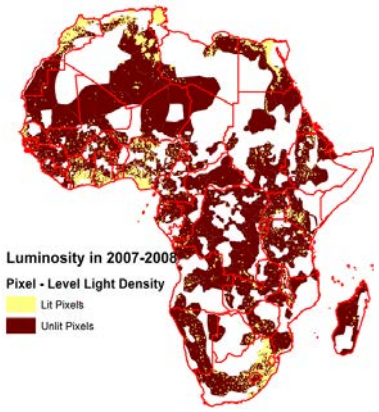

Figure 9*a*

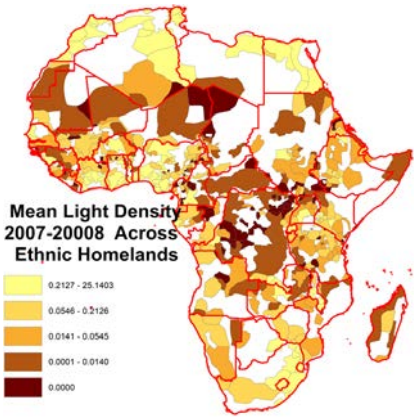

Figure 9*b*

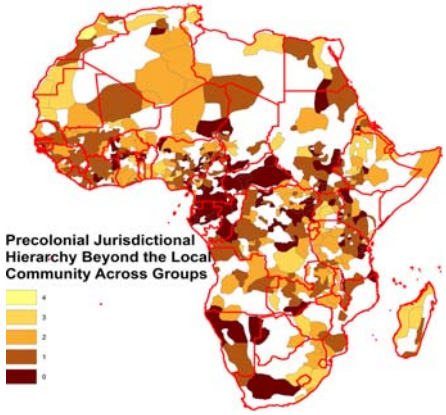

Figure 9*c*

Moscona, Nunn, and Robinson (2017) explore the contemporary legacy of ethnic-specific precolonial family structures across Africa. Specifically, they test whether ethnicities organized

[19] The within-country influence of historical institutions and precolonial political centralization in particular has been subsequently shown in the context of Latin America (Chiovelli (2014), Angeles and Elizalde (2017)), in North America (Dippel (2014)), and in Vietnam (Dell, Lane, and Querubin (2017)). In the latter, the authors look at a specific border between the centralized Dai Viet and the noncentralized Khmer (Cambodian) Empire and shed some light on the channels by showing that in villages with a strong historical state, citizens, thanks to a stronger civil society reflected in the quality of the local governments, have been better able to provide public goods and redistribution, suggesting a complementarity between political centralization and pro-social norms. In an another recent paper, Heldring (2016) documents a positive association between regions' experience with precolonial kingdoms and contemporary public goods within Rwanda; however, he highlights the potentially negative aspect of state capacity, showing that mobilization towards state-sponsored violence during the genocide was more successful in precisely the same locations. Besley and Reynal-Querol (2014) associate historical conflict, often among large precolonial African kingdoms, with contemporary violence.

around "segmentary lineages" are more prone to violence and conflict by combining anthropological data from Murdock (1967) and contemporary GIS data on conflict. This empirical investigation is motivated by the ethnographic record, suggesting that in such societies, individuals are expected to come to the defense of fellow lineage members when the latter get involved in conflicts. As a consequence, small disagreements can quickly escalate to larger-scale conflicts. Employing within-country variation and RD specifications that look at ethnic boundaries between segmentary and nonsegmentary groups, they find evidence in support of the ethnographic record.

Historical Kingdoms in Europe Studies on the shadow of historical boundaries increasingly focus on Europe. On the one hand, Europe features some of the oldest modern states where the implementation of strong nation-building policies has given rise to countries close to the Weberian ideal states, with significant state capacity where statewide policies are effectively implemented. So, sharp within-country spatial discontinuities in economic activity in this part of the world seem unlikely. On the other hand, Europe has the advantage of featuring a rich political legacy, producing a potentially large set of historical political boundaries.

Oto-Peralías and Romero-Avila (2017) focus on the stable frontier between Castile and the Nasrid Kingdom of Granada in the late Middle Ages. They show that land inequality and concentration of wealth are higher on the Castilian side, both today and during the 18th century. They attribute this difference to the fact that the military insecurity of the frontier region of Castile favored the concentration of economic and political power to remain jurisdictionally viable.

Studies also explore the legacies of the Ottomans and the Habsburgs, looking at the historical borders of these empires and across their administrative regions. Schulze and Wolf (2009) find that even before the Great War, there were "border"effects within the Austro-Hungarian empire regions, which can be explained by the ethnolinguistic composition of the regional capitals.[20] Becker, Boeckh, Hainz, and Woessmann (2016) compare communities on both sides of the Habsburg border within several eastern European countries that have shared common formal institutions for a century now. They find that historical Habsburg affiliation increases current trust and reduces corruption in courts and police. Grosfeld and Zhuravskaya (2015) look at discontinuities across regions of Poland that used to be split between three empires (Russia, Austria, and Prussia) to look at their legacy, documenting sizable inertia.

Grosjean (2011) examines the Ottoman legacy in exploiting regional variation in development within six southeastern European countries that were partly occupied by the Ottoman

[20] The trade-diverting role of ethnolinguistic networks is also found by Aker, Klein, O'Connell, and Yang (2014) who look at market integration in Niger across both international and ethnic boundaries.

Empire. Her analysis reveals that financial development proxies are considerably lower in Ottoman-ruled areas. Grosfeld, Rodnyansky, and Zhuravskaya (2013) assess the role of the Holocaust in exploiting spatial variation in Russia. Employing a spatial regression discontinuity design, they find that in areas inside the pale of settlement, where Jewish communities were confined during the Tsarist times, there is less entrepreneurship and less support for democracy, and citizens are more likely to support communism, though individuals exhibit higher levels of trust.

3.3 Caveats using Spatial Regression Discontinuities

3.3.1 Omitted Variables

Conducting the analysis at the ethnic homeland, concession, historical kingdom, or district level or looking at historical boundaries is, however, not a panacea. The compared units may be different along many dimensions. For example, ethnic groups or colonial concessions may differ in more than the degree of political complexity or intensity of violence, respectively. By implementing spatial regression discontinuity designs, essentially comparing adjacent regions along the boundaries, one successfully accounts for factors that vary smoothly in space and hence mitigate concerns related to bias arising from variation in geographic elements. Nevertheless, such estimates do not take into account other potential differences at the group, historical entity, or concession level. To account for the latter and unpack the bundle of traits that may vary across entities, researchers add other entity-specific traits from the ethnographic, historical, and colonial record, respectively.

3.3.2 Spatial Spillovers

Another angle that is crucial to keep in mind in explorations on spatial development is that the treatment studied in one spatial unit may exert an effect on other spatial units that serve as the control group (Miguel and Kremer (2004)). The potential of positive and negative spatial externalities is an important dimension that researchers using high-resolution spatial data need to keep in mind. Migration, sorting, and selection affect most units, making the treatment-control distinction less clear-cut. This issue of whether the consequences of a given "treatment" in a location may directly influence outcomes elsewhere is particularly important for constructing counterfactual scenarios based on local estimates as well as aggregating the economic consequences of these local events. One approach is to account for spillovers in an adhoc manner (e.g., Michalopoulos and Papaioannou (2016)) or by employing spatial econometric techniques that model spillovers (e.g., Harari and La Ferrara (2014)). Another approach is to explicitly model spatial dependence across units in the context of general equilibrium network models.

See, for example, Allen and Arkolakis (2014), Acemoglu, García-Jimeno, and Robinson (2015), Donaldson and Hornbeck (2016), and Desmet, Nagy, and Rossi-Hansberg (2016). Given the strong interdependence of spatial units within countries in terms of labor and capital mobility as well policy choices, more studies considering the equilibrium responses in the context of a network are needed.

3.3.3 External Validity and Heterogeneity

Focusing on specific borders to conduct inference has the advantage that one may bring into the picture a great deal of the institutional details of the phenomenon being studied.[21] Nevertheless, generalizing from case studies can be misleading, echoing the usual "external validity"arguments readily invoked in the context of micro-development. In Michalopoulos and Papaioannou (2014) we highlight how focusing on a single national border discontinuity can lead to erroneous conclusions, given the substantial heterogeneity in the degree to which national institutions translate into differences in economic performance straddling national boundaries in Africa. Hence, understanding the forces behind the heterogeneous outcomes of a given treatment is the direction that is likely to deliver relatively generalizable lessons on the roots of development. Campante and Yanagizawa-Drott (2017), for example, uncover the heterogeneous effect of air links on global inequality by establishing that international long-distance flights increase economic activity (reflected in satellite-measured night lights) only when connecting high-income to middle-income (but not low-income) countries.

3.3.4 Endogeneity of Ethnicity and Historical Borders

The assignment of ethnicities into specific territorial boundaries and of people into broad ethnic categories are challenging tasks. Ethnic or historical boundaries are often more fluid than sketched, as historical kingdoms faced challenges in broadcasting power in remote areas (Herbst (2000)). There is also a wide debate among social scientists regarding the malleability of ethnicity. On the one hand, there is scholarship on how colonizers and postcolonial state builders have manipulated the ethnic landscape, stressing the socially constructed and time-varying nature of ethnic identity. On the other hand, there is a stream of research that treats ethnic groups as relatively stable social units that shape the economic and political environment.[22] For example, the fact that geographic and epidemiological factors are robust predictors of the

[21] Effectively used, this wealth of information can help overcome the criticism launched among historians regarding the tendency of economists to compress both time and history, linking causes and effects often centuries apart (see Hopkins (2009) and the thorough response of Fenske (2010).

[22] This debate has a venerable intellectual history of two main strands of thought: the primordialists who treat ethnic groups as deeply rooted clearly drawn entities (Geertz (1967)), and the constructivists or instrumentalists, who highlight the contingent and situational character of ethnicity (Barth (1969)).

degree of contemporary ethnic diversity highlights the sources of stability of these social entities Michalopoulos (2012) and Cervellati, Chiovelli, and Esposito (2017).

3.3.5 Invariance to Scale

A well-known issue in spatial studies relates to the modifiable areal unit problem (MAUP). The essence of MAUP is that the shape and scale of the spatial unit chosen crucially influence the statistics resulting from aggregating the underlying measure of interest, initially available at a finer scale. For example, luminosity data may be aggregated into postal code areas, coarser administrative units, counties, or any other arbitrary partition, such as ethnic homelands, religious areas, or "pixels" (thus, the areal units are modifiable). The MAUP is one of the better-known problems in geography and spatial analysis, as data aggregation might obscure a correlation between variables or make unrelated variables appear correlated. So, researchers using GIS data and conducting spatial analyses should examine the robustness of the results to different levels of aggregation. This is computationally feasible since luminosity and other big spatial data are available at a fine resolution. See Michalopoulos (2012) for a thorough treatment of the MAUP in the context of establishing a robust link between geographic heterogeneity and ethnolinguistic diversity.

Reynal-Querol and Montalvo (2016) examine at various levels of spatial aggregation the relationship between ethnic diversity and economic performance, as reflected in luminosity. Their analysis illustrates the usefulness of conducting the analysis at various aggregation levels. Starting from the country level, and as long as the spatial units are fairly large, there is a negative relationship between ethnic diversity and economic performance (a finding that is in line with the seminal work of Easterly and Levine (1997)). However, this relationship weakens and even changes sign as the unit of analysis becomes smaller. The robust negative relationship at coarse levels is consistent with the notion that ethnically diverse societies find it difficult to coordinate on cohesive institutions and suffer from the underprovision of public goods. However, in a given country, the coexistence of people from different ethnic backgrounds may bring economic benefits, for example, by having a denser network of markets in ethnically diverse territories. Indeed, the authors show that markets are more likely to be located along ethnic boundaries within African countries, partially rationalizing the positive aspect of ethnic diversity locally. More generally, the study of Reynal-Querol and Montalvo (2016) suggests that the cross-country correlates of growth and development may not necessarily translate to similar associations at finer units of aggregation within countries.

Sometimes the instability of a pattern due to the change in the spatial unit may also suggest that there is something unique about the spatial unit considered. So, an alternative

way to gauge whether a given set of spatial units (zones) is critical for the obtained relationship is to show that small perturbations of the initial set of boundaries may deliver noisier or no results. Alesina, Michalopoulos, and Papaioannou (2016) employ such a technique to show that it is indeed ethnic inequality measured by the original linguistic boundaries that matters for development. They construct alternative indexes of inequality based on Thiessen polygons that have the exact same centroids as the actual linguistic and ethnic homelands in the Ethnologue and GREG databases, respectively, the key difference being that the actual homelands have idiosyncratic shapes.[23] Briant, Combes, and Lafourcade (2010) evaluate the magnitude of the distortions arising from the MAUP on the analysis of spatial concentration, agglomeration economies, and trade determinants using various French zoning systems. They find that the size and shape of these spatial units are of secondary importance compared to specification issues.[24] On the contrary, Coughlin and Novy (2016) show that estimates of the standard gravity model crucially depend on the level of spatial aggregation of the underlying trade data. Cervellati, Chiovelli, and Esposito (2017) and Alsan (2015) conduct their analysis on the impact of the ecological suitability of malaria and the tsetse fly at various levels of spatial aggregation, cleanly addressing the MAUP.

4 Concluding Remarks

We reviewed works of an emerging meso approach in growth and development economics that uses fine-resolution spatial proxies of development, such as satellite images of light density at night, and exploits variation across administrative regions, ethnic homelands, historical kingdoms, and pixels of various sizes. This body of research tries to balance the merits and drawbacks of macro cross-country studies, which suffer from various sorts of endogeneity (omitted variables, error in variables, and reverse causation), and micro works, which advance on causation by randomization but often lack generalizability. We discussed studies that employ spatial regression discontinuity designs and use a plethora of historical accidents (such as the delineation of colonial boundaries) to advance on identification and shed light on general-interest questions, such as the role of colonial institutions, the lasting impact of empires in Europe, and the role of ethnic diversity, among others. This vibrant research agenda has been fostered by the availability of GIS data on luminosity and various geographical-ecological features produced by geographers and earth scientists. Economists have combined this information with historical maps, anthropological, and archival records including historical censuses to assess a

[23] Thiessen polygons have the unique property that each polygon contains only one input point, and any location within a polygon is closer to its associated point than to a point within any other polygon.

[24] For an introduction to the econometric issues arising from large, typically spatial datasets, see Varian (2014) and Gibbons, Overman, and Patacchini (2015).

broad set of issues and shed light on the fundamental drivers of economic activity around the world.

This meso approach is not problem free, and we discuss its pitfalls. Yet, we believe that the amalgamation of big spatial data, coupled with increases in computing power and advances in theoretical and empirical spatial econometric techniques, offers new directions for this type of research. On the data front, there are already studies that use fine-resolution information on various aspects of economic activity. To name a few, recent works have used GIS data on civil conflict and violence (e.g., Harari and La Ferrara (2014), Berman, Couttenier, Rohner, and Thoenig (2017), Michalopoulos and Papaioannou (2016), Besley and Reynal-Querol (2014)) produced by news aggregators and political scientists (UCDP-GED and ACLED). A vibrant new research uses social media (Facebook and Twitter) data (e.g., Enikolopov, Makarin, and Petrova (2016), Acemoglu, Hassan, and Tahoun (2017), Enikolopov, Petrova, and Sonin (2017)). Google search information has been used to measure labor market dynamics in industrial countries. Cell phone and Internet penetration and usage have been linked to education and protests in Africa (e.g., Manacorda and Tesei (2017), Hjort and Poulsen (2017)). Satellite-based land use data also provide a fruitful avenue for future research (Burgess, Hansen, Olken, Potapov, and Sieber (2012)). Marx, Stoker, and Suri (2016) use satellite images to infer the quality of housing in slums.

We believe that future research will take a holistic approach. That is, instead of using a particular dataset (say, luminosity or mobile telephony) to test a conjecture or theory, researchers will use multiple proxies and, perhaps more interestingly, combine the available proxies to gain a better understanding of local development outcomes and to shed light on the mechanisms at play.

This meso approach does not imply that country-level policies do not matter. Nationwide decisions do determine a great deal of public goods and state capacity remains lodged at the level of the nation state. Nevertheless, the local take up and eventual impact of a given national policy may crucially depend on a host of location-specific factors that the meso approach aims to highlight. Moreover, among the United Nations millennium development goals set by the General Assembly, the decentralization of various aspects of central governance is prominently featured. As efforts towards decentralization gain momentum in the developing world we expect the meso approach to be useful for practitioners in identifying frictions and impediments as well offer guidance on what policies may or may not work on the ground and why.

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