Democracy and Light:
Electoral Accountability and the Provision of Public Goods

Brian Min†
Department of Political Science
University of California, Los Angeles
bmin@ucla.edu

This Version: April 28, 2008

PLEASE DO NOT CITE
COMMENTS WELCOME

Abstract

Do democracies provide more public goods than autocracies? Clear answers to this question have been hampered by inconsistent, unreliable, or missing data. To address the shortcomings of self-reported government data, I propose a novel method to generate unbiased estimates of the provision of electrical infrastructure across the entire globe using satellite imagery of nighttime lights. After demonstrating the validity of my measure, I show that democratization is associated with a substantial decrease in unelectrified populations, even after controlling for differences in per capita income, population density, and other factors. Complementing the cross-national results, I use a difference-in-differences estimator applied to the former Soviet Bloc to show that democratization has positive effects on electrification over time. The results affirm the power of electoral incentives in inducing democratic leaders to provide higher levels of public goods than in autocracies where leaders do not need to win elections.

1 Introduction

If democracies are better at providing public goods than autocracies, why do 57% of India's citizens lack electricity compared to fewer than 2% in China? According to official sources, access to basic electrification is dramatically lower in India than in China, despite similarly massive populations, large territories, and expanding but impoverished rural economies.[1] For theories that expect democracies to provide more public goods (Lake & Baum 2001, Bueno de Mesquita et al. 2003) and to distribute them more efficiently (Wittman 1989, Gradstein 1993) and equitably (Weingast, Shepsle & Johnsen 1981, Collie 1988), the track records of the world's most populous democracy and autocracy represent either an exceptional anomaly, indicate a limitation of our theories, or suggest that the data underlying these claims are unreliable.

Using a novel set of satellite imagery of the earth at night, this paper examines the distribution of electrification across democracies and autocracies to test theories of electoral accountability linking regime type to the provision of local public goods. Unlike traditional data sources, the new satellite-derived estimates are unbiased by political factors, consistent in its measurement technique across all countries, and complete in its data coverage across the entire world. As a result, the data allow

†I have benefited greatly from discussions with Lars-Erik Cederman, Tom Gillespie, Miriam Golden, Tim Groseclose, Daniel Posner, Anoop Sarbahi, Anna Sher, Rein Taagepera, and Andreas Wimmer. An earlier version of this paper was presented at meetings at UCLA, UC Santa Cruz, and UC Irvine. I am grateful for financial support from the Institute on Global Conflict and Cooperation and the Institute of American Cultures. All errors are my own.

[1]For example, see the widely used data reported in International Energy Agency (2002) and the data underlying World Bank statistics collected by Canning (1998).

for a more credible analysis of how governments differ in the provision of a basic public service that 1.6 billion continue to lack (International Energy Agency 2002).

The new data reveal a large and significant positive effect of democracy on the provision of electrification that is unlikely to have been produced by chance or by differences in country wealth, demographics, natural resources, or geography. Complementing the cross-sectional results, I show that democratization leads to increased electrification over time by exploiting a quasi-natural experiment of regime change in the former Soviet Bloc after the fall of Communism. These results are especially surprising given that they cannot be replicated using "official" statistics on electrification which rely on traditional data collection strategies including government self-reports.

The paper proceeds as follows. In the next section, I discuss theories of local public goods provision. After discussing the role of the state in providing electrification, I introduce the satellite data and describe the method to estimate the level and distribution of electrification around the world. Using regression analysis, I next present cross-national evidence showing that democracy is associated with a significant and substantial decline in unelectrified populations and also present a difference-in-differences estimation evaluating changes in electrification across the former Soviet Bloc. I end with some concluding observations.

2 Explaining the Provision of Local Public Goods

Basic infrastructure and public services are the building blocks of development. Places without electrification, clean water, public health, and education are unlikely to escape from poverty or foster high quality of life. Yet even given their high social and economic value, basic infrastructure and public services are difficult to supply. Theories of collective action show that when the benefits of basic services are broad, the incentive for individuals to contribute to their costs are low. As group size increases, the costs of provision scale up just as the incentives to contribute scale down. Free-riding problems undermine the incentive for voluntary collective action and infrastructure and basic public services go underprovided.

Governments are unique in their ability to raise revenues and coordinate expenditures, and thus the central role they play in the provision of public services is widely acknowledged. Yet there is no consensus on what kinds of governments provide basic infrastructure and services most effectively. Institutional theories emphasize the role of political institutions in creating different incentives for democratic and autocratic leaders to provide public goods and services. Democratic leaders are expected to differ in their behavior in office because they are held accountable by voters for their performance. Lipset (1959, p. 71) defines democracy "as a political system which supplies regular constitutional opportunities for changing the governing officials, and a social mechanism which permits the largest possible part of the population to influence major decisions by choosing among contenders for political office." Elections provide voters with the power to replace their leaders when they do not serve the best interests of the public. Similarly, Schmitter & Karl (1991, p. 76) argue that "modern political democracy is a system of governance in which rulers are held accountable for their actions in the public realm by citizens."

Given the mechanism of electoral accountability that is embedded in democracy, it is natural to assume that democratic leaders should be more responsive to the needs of its citizenry than dictators who do not face competitive elections. To stay in office, democratic politicians must convince their constituents that they are better able to serve their needs than any other challenger. Because democratic politicians are likely to be evaluated on their ability to provide basic benefits, democratic leaders should provide higher levels of local public goods than dictators (Lake & Baum 2001). Elections also invite a larger portion of the citizenry to participate in the selection of their leaders than in non-electoral environments. As Gandhi & Przeworski (2006, p. 2) state "dictators are dictators because they cannot win elections." Thus, democratic leaders must secure a much broader base of political support than autocrats. When the size of the minimum winning coalition is large, Bueno de Mesquita et al. (2003) argue that provision of public goods is more cost effective than private transfers to win support. A similar theme is echoed by Acemoglu & Robinson (2006, p. 18) who state: "We argue that democracy, which is generally a situation of political equality, looks after the interests of the majority more than nondemocracy, which is generally dominated by an elite and is more likely to look after its interests. Stated simply and extremely, nondemocracy is generally a regime for the elite and the privileged; comparatively, democracy is a regime more beneficial to the majority of the populace, resulting in policies relatively more favorable to the majority." Given the institutional incentives of democracy, elected leaders are more likely to invest in the provision of broad-reaching classes of public goods and services than dictators.

Yet despite this clear theoretical expectation, competitive elections alone might fail to induce politicians to provide an efficient level of public goods provision. The relatively short time horizons faced by elected leaders might decrease the incentive for longer term investments in capital projects and other services that take years to build. Touting the success of Singapore's state-planned economy, Lee Kuan Yew describes, "Our job was to plan the broad economic objectives and the target periods within which to achieve them. Infrastructure and the training and education of workers to meet the needs of employers had to be planned years in advance" (Lee 2000, p. 66). Meanwhile, the logic of majority rule might lead to the persistent deprivation of peripheral minority groups who never enjoy the spoils of office (Guinier 1994). And a bevy of country studies have observed many pathologies in otherwise democratic settings. In her study of the power of political machines in Argentina, Stokes (2005) suggests that when democratic leaders have the ability to monitor constituents votes, a "perverse" accountability takes over, and rather than practicing oversight, citizens use their vote to seek out rewards and avoid punishment. Clientelistic and patrimonial practices are said to undermine the supposed virtues of electoral accountability across the developing world (see e.g., Bratton & van de Walle 1994, Chandra 2004) as well as in the industrialized world (see e.g., Scheiner 2006).

While democracies are expected to produce more local public goods, there is less consensus on whether democracies distribute them any differently than autocracies. According to some, the political competition associated with democracy should yield efficient and equitable policy outcomes (Wittman 1989, Gradstein 1993). Median voter theory suggests that if the median voter has less income than the average voter, governments will be larger with more social expenditures benefiting the poor (Meltzer & Richard 1981). Given that the income distribution is typically skewed towards the high end of the spectrum in most countries, democracy should thus benefit the poor. Lindert (2004) finds strong historical evidence that democracy leads to an increase in redistributive spending. Many note that democracies seem to work harder to meet the needs of historically disadvantaged groups (Pande 2003).

Explicit models of legislative behavior pivot around whether lawmakers cooperate or not in deciding distributional allocations. Non-cooperative models assume that public good distributions are decided by minimum winning coalitions in legislatures. Since the votes of those outside the coalition are not necessary to maintain power, only those within the power-holding alliance will have a say in determining public spending. Implicitly, legislative districts outside of the minimum winning coalition are unlikely to receive the same level of public spending as districts within the coalition. This logic is a central feature to many models of vote buying and coalition formation (Austen-Smith & Banks 1988, Baron & Ferejohn 1989). On the other hand, a cooperative legislative norm is likely to induce much broader distributions of public goods. Inspired by observations of legislative log-rolling in the U.S. Congress, Weingast, Shepsle & Johnsen (1981) propose that resource allocation will obey a norm of universalism in which each district gets what they want so long as all other districts do as well. Larger legislative coalitions may also be likely because they are cheaper to maintain (Groseclose & Snyder 1996) and because of strategic interaction between politicians and voters (Besley & Coate 2003).

Empirical support for the distributional benefits of democracy has been mixed. Many cross-national studies do not find systematic evidence that the higher levels of social expenditures made by democracies actually reach the poorest or most vulnerable segments of society (Keefer 2005, Ross 2006). Keefer & Khemani (2005, p. 2) observe that "policymakers in poor democracies regularly divert spending away from areas that most benefit the poor or fail to implement policies that improve the services that are known to disproportionately benefit poor people." A recent evaluation of 120 World Bank rural electrification projects reports that "the larger share of benefits from rural electrification is captured by the non-poor" (World Bank 2008, p. xv). Some argue that representative democracies are vulnerable to several types of "political failures" and are unlikely to produce economically efficient distributions (Besley & Coate 1998).

A separate literature emphasizes the ability of some citizen groups to overcome collective action problems because of shared preferences or the presence of social norms that punish defectors and free-riders. These arguments suggest that groups can overcome coordination problems where social capital is high, perhaps by the presence of civil society groups (Boix & Posner 1998, Tsai 2007) or because of shared kinship networks (Bates 1974). In this context, places where a voting bloc can credibly communicate their policy preferences are more likely to receive the local public goods they want. Empirical research has linked higher ethnic diversity to lower public goods provision at both the cross-national (Easterly & Levine 1997, Posner 2004, Montalvo & Reynal-Querol 2005) and sub-national levels (Alesina, Baqir & Easterly 1999, Wantchekon 2003, Besley et al. 2004, Miguel 2004, Banerjee, Somanathan & Iyer 2005).

Yet both the institutional and social capital theories explain only a portion of the variance in the distribution of public goods in the developing world: greater variation exists on the dependent variable than in electoral institutions; and the mechanisms by which ethnic diversity affect public goods provision are not well understood (Habyarimana et al. 2007). The result is that the provision of public goods remains poorly understood in the developing world, even though politics plays a dominant role in the distribution of public infrastructure in rural lands.

Drawing on new detailed data on the provision of electrification, this paper seeks to identify and measure differences in the provision of a critical local public good across democracies and dictatorships. While many scholars have evaluated the differences in electoral rules across democracies, these differences are likely to be small compared to the expected variation across regime types, which I focus on here.[2]

If governments are accountable to voters in democracies, than all else equal, politicians who increase voter welfare by providing more public goods should fare better in elections than those that do not. This accountability mechanism suggests a long-term positive effect of democracy, since incumbents who fail to act in the best interests of voters are likely to be replaced. The central hypothesis evaluated here is that over the long-term, countries under democratic rule where political leaders are regularly evaluated at the polling booth should have more citizens enjoying the benefits of basic public services and goods than those living in autocracies.

[2]For studies of within-democracy differences, see Persson & Tabellini (2000), Lizzeri & Persico (2001), Milesi-Ferretti, Perotti & Rostagno (2002), and Persson & Tabellini (2003); for differences across autocracies, see Gandhi & Przeworski (2006)).

3 Electrification and the State

Electricity and lighting is ubiquitous across the industrialized world. But more than a century after the introduction of electric power transmission, at least a quarter of the world's population still live without electricity and rely instead on kerosene, wood, and agricultural residues to meet their energy needs (International Energy Agency 2002). More than simply a modern convenience, access to electricity is a life-altering transformation that improves quality of life and enables economic development. Electric light extends a day's productive hours, allowing children to study after the sun has set and enhancing the safety of women at night. Refrigeration allows for the preservation of food and medicines. Powered water pumps reduce the effort needed to collect clean water. Electrical cooking stoves reduces the amount of time needed to gather wood and other biomass fuels.[3] Electrical power enables the development of industries and creates new jobs. For communities, electrification improves safety at night via streetlights, enables irrigation and drainage systems to improve agricultural productivity, and encourages entrepreneurship.

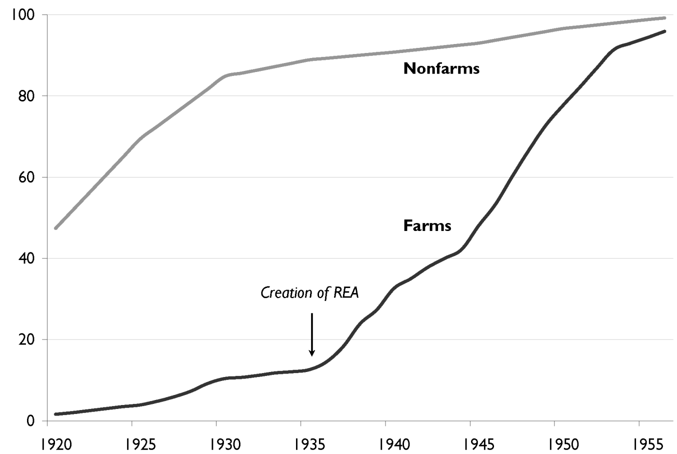
No country has ever completed rural electrification without the intensive financial support of its government (Barnes & Floor 1996, p. 519). At the founding of the Soviet Union in the 1920s, Vladimir Lenin famously placed electricity at the center of his vision of the future: "Communism is Soviet power plus the electrification of the whole country." His State Commission for Electrification of Russia (GOELRO) sought to extend the power grid to the entire country and formed the basis of the first Soviet plan for national economic recovery. The plan reflected Lenin's belief in a reorganized industry based "...on electrification which will put an end to the division between town and country and ... overcome, even in the most remote corners of land, backwardness, ignorance, poverty, disease, and barbarism." Implementation of GOELRO led to a near doubling of the country's total national power output by 1931 (Kromm 1970) and full electrification of the entire Soviet Union in the years that followed. Meanwhile, in Germany, Holland, and Scandinavia, the electrification of every home was seen as a desirable political goal and 90% of homes were electrified by 1930 (Nye 1992, p. 140).

In the U.S., however, electric power distribution had been dominated by private utilities who focused their business in urban centers. Extending the power grid from cities to rural areas requires high fixed cost investments in infrastructure including new power plants, long haul transmission lines, substations, and shorter distribution lines to the end user. Rural areas with low customer densities were unattractive markets to profit-minded firms. By the time of the Great Depression, only one in ten rural Americans had access to electricity compared to 90% of city dwellers. With the collapse of the economy, even private power utilities in the most lucrative urban markets were struggling to stay solvent. Farmers seemed destined to stay in the dark had it not been for Franklin Roosevelt's celebrated establishment of the Tennessee Valley Authority (TVA) in 1933 and Rural Electrification Administration (REA) in 1935. At the end of 1934, only 12.1% of all U.S. farms had electricity, while only 3% were electrified in Tennessee and less than 1% in Mississippi. By 1943, the TVA and REA had brought electricity to four out of ten American farms (see Figure 1). Within one more decade, nine out of ten were connected (U.S. Census Bureau 1975, p. 827). Former U.S. Secretary of Agriculture Bob Bergland recalled, "The day the lights finally came on at our farm, I remember my mother cried." Another farmer reminisced, "I remember singing with robust glee in celebration as our little strip of houses along a dirt road was connected to electricity. We sang out with joy and no small amount of amazement: Oh the lights, the lights, Lottie Mae got light and we got lights! Oh the lights, the lights."[4]

[3] In rural Africa, many women carry 20 kilograms of fuelwood an average of 5 kilometers every day (International Energy Agency 2002, p. 367).

[4] Campbell, Dan, "When the lights came on," `http://www.rurdev.usda.gov/rbs/pub/aug00/light.htm`

Figure 1: Electrifying America: Percentage U.S. dwelling units with electricity, 1920–1956



Source: U.S. Census Bureau, Historical Statistics of the United States, 1975, S 108-119.

Outside of the industrialized world, electrification has been pursued with uneven ambition and success. In China, purposeful government policies have led to the claimed electrification of 700 million people's homes over the last two decades — an achievement of unprecedented scale and scope. In one program promulgated in State Council Document No. 190 in 1983, local development of rural hydropower facilities was mandated in 100 mostly remote rural counties and funded through subsidies and low-interest loans. By 2000, an additional 553 counties had also been electrified through the program, bringing the total number of beneficiaries of rural hydropower to nearly 140 million people. Overall, total electricity consumption in rural China increased tenfold between 1978 and 2000. The number of villages without electricity decreased from 55,000 in 1993 to 9,300 in 2002. According to official estimates, over 98% of Chinese homes have an electrical connection today (SHP News 2004, Pan et al. 2006).[5]

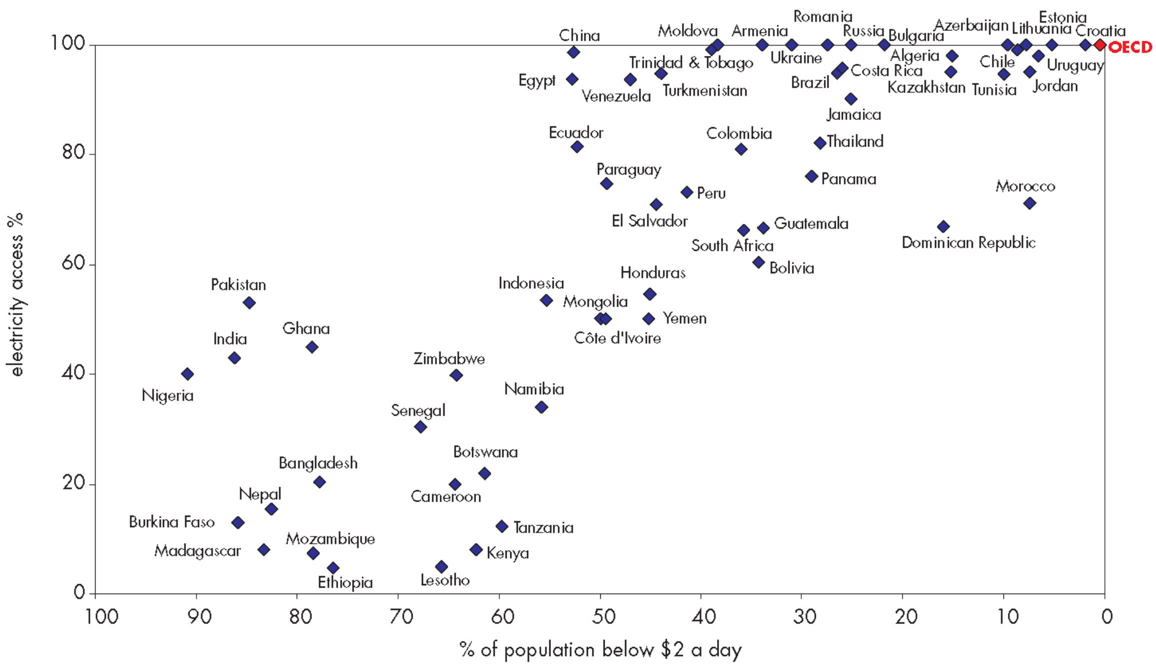
Meanwhile just west of China in the world's most populous democracy, India has struggled mightily to electrify its rural lands. More people in India lack electricity than anywhere else in the world, accounting for a third of the world total. Half a billion Indians living in over 100,000 villages still had no electricity as of 2005. Several government efforts have sought to electrify India's rural villages. In the late 1990s in Uttar Pradesh, Chief Minister Mayawati initiated the Ambedkar Village program (Ambedkar Gram Vikas Yojana) to provide over 11,000 of the poorest villages with electrification, roads, and irrigation. The program was widely regarded as a targeted effort to win Scheduled Caste votes and was closely associated with Mayawati and her Bahujan Samaj Party (BSP).[6] Despite its intentions to alleviate poverty, the project has been criticized for its blatant politicization of caste differences. Some in the media have characterized the program as a mismanaged "pet" project of Mayawati's, reflecting her "obsession with the Dalit agenda."[7]

[5]Interestingly, the satellite-derived estimates I describe below observes a much higher proportion of the Chinese population living without reliable electricity.

[6]The BSP was founded in 1984 to consolidate caste and religious minority interests in India. As a staunch advocate of Scheduled Caste issues, it has been most successful in Uttar Pradesh where it won nearly 60% of the Scheduled Caste vote in 1998 (Chandra 2004). The Ambedkar program gets its name from B.R. Ambedkar, an untouchable who rose to prominence as a jurist and architect of the Indian constitution in the post-independence period.

[7]Tripathi, Purnima S., "Mayawati in Deep Trouble," Frontline, Volume 19, Issue 19, September 14-27, 2002.

Figure 2: Official estimates of electricity access and poverty, 2000



Source: International Energy Agency (2002, p. 375)

The Ambedkar Village program's implementation showcases the powerful role of patronage in Indian politics. The program has been accused of mismanagement and corruption ($50 million or 1/3 of program spending could not be accounted for, presumably lost to kickbacks and fraud). During the 1997 to 2001 period, audits revealed that numerous villages had been illegitimately electrified. In the Barabanki district just east of Lucknow, six villages that had not been authorized to receive electrification funds were nonetheless electrified. Several other villages were found to have been selected for electrification by intervention of the Energy Minister, contrary to program guidelines (Wilkinson 2006).

Similar patterns of politically motivated public goods provision have also been documented in Mexico. A massive poverty alleviation program, PRONASOL (Programa Nacional de Solidaridad), began in 1989 to provide or improve access to water, electricity, nutrition, and education in poor communities. Municipalities dominated by the ruling Institutional Revolutionary Party (PRI) received significantly higher per capita transfers than those voting for another party (Diaz-Cayeros, Magaloni & Estévez forthcoming).

While access to electricity is certainly related to a country's level of development, the relationship is not absolute. The International Energy Agency (IEA) produces the most cited source of data on electrification levels around the world in its annual World Energy Outlook series. As the IEA data in Figure 2 show, many countries with comparable poverty levels have very different levels of electrification. The percentage poor in Bolivia and Armenia are identical but less than two-thirds of Bolivians have electricity compared to universal access in Armenia. Pandemic poverty in Nigeria is associated with higher levels of electrification than in Kenya. The Dominican Republic has lower levels of poverty than Jamaica but much lower levels of electrical provision. These variations suggest that while the level of development is important, it alone does not explain why some states are better able to provide electrification than others.

The IEA data also illustrates some of the potential weaknesses that affect many commonly used datasets in cross-national analysis. Given the impossibility of manually collecting data using a single consistent and coherent process across the world, IEA's data are derived from dozens of sources, including self-reported government data, NGO estimates, World Bank studies, and regional organization reports. Since no universal definition of electricity access exists, the comparability of country-specific estimates is difficult to gauge. Official definitions of electrification can differ even within the same country. For decades in India, a village was officially declared electrified if it had a single electrical connection used for any purpose. But in 2004, the official definition changed, requiring the presence of basic infrastructure, electrification of public buildings, and at least a 10% household electrification rate. As an artifact of this definitional change, official government reports show an improbable decline in India's village electrification rates over the last decade. In addition to differences in methodology in data collection, the bureaucratic capacity to collect dependable statistics varies by country. It is likely that the precision and reliability of electrification estimates is lower in poorer countries, places overwhelmed by civil war, and closed regimes inaccessible to outsiders. Finally, the IEA lists data for only 85 countries, resulting in missing data that is unlikely to be random.

4 Measuring Electrification from Above

High levels of uncertainty pervade official estimates of the portion of the global population without access to electricity, a vital and basic public service that is typically provided by governments in most of the rural world. I propose a new method to estimate the provision of electrification that relies on the analysis of satellite images of the earth at night to identify all lit and unlit populated areas across the globe. Since 1970, the Defense Meteorological Satellite Program's Operational Linescan System (DMSP-OLS) has been flying in polar orbit capturing high resolution images of the entire earth each night between 20:00 and 21:30 local time. Captured at an altitude of 830 km above the earth, these images reveal concentrations of outdoor lights, fires, and gas flares at a fine resolution of 0.56 km and a smoothed resolution of 2.7 km.

Beginning in 1992, all DMSP-OLS images were digitized, facilitating their analysis and use by the scientific community. While daily images are available, the primary data products used by most scientists are a series of annual composite images. These are created by overlaying all images captured during a calendar year, dropping images where lights are shrouded by cloud cover or overpowered by the aurora or solar glare (near the poles), and removing ephemeral lights like fires and other noise.[8] The result is a series of images of time stable night lights covering the globe for each year from 1992 to 2006 (Elvidge et al. 1997*a*, Imhoff et al. 1997, Elvidge et al. 2001). Since the DMSP program may have more than one satellite in orbit at a time, some years have two annual images created from composites from each satellite, resulting in a total availability of 23 annual composite annual images. Images are scaled onto a geo-referenced 30 arc-second grid (approximately 1 km^2). Each pixel is encoded with a measure of its annual average brightness on a 6-bit scale from 0 to 63. These are relative values and thus individual pixel values are not directly comparable from one year to the next. This does not affect the analysis of variation within a single annual composite image as I present here.

Figure 3 shows a reverse-color DMSP-OLS image of night-time lights in 2003 with darker dots indicating more brightly lit areas and white areas on the page indicating darkness. The image

[8]The geographic extent of usable DMSP data is -65 to +65 latitude. This results in missing data for portions of the world within the Arctic and Antarctic circles (home to only 0.0005% of the global population).

reveals large variation in light intensity around the world, with especially broad and brightly lit areas across the eastern U.S., western Europe, India, and east Asia. Meanwhile, inhospitable environments in the frozen Arctic deserts of Canada, Alaska, and Siberia and the hot deserts of Africa, China, and Australia are cloaked in darkness. At first glance, the distribution of lights might appear to be a reflection of population distributions. But closer examination reveals that there are important differences across the world and within countries. For example, much of Africa is dark, even though it is home to 15% of the world's population. While more than one in three people in the world live in India and China, their light output accounts for only a tenth of the global total.

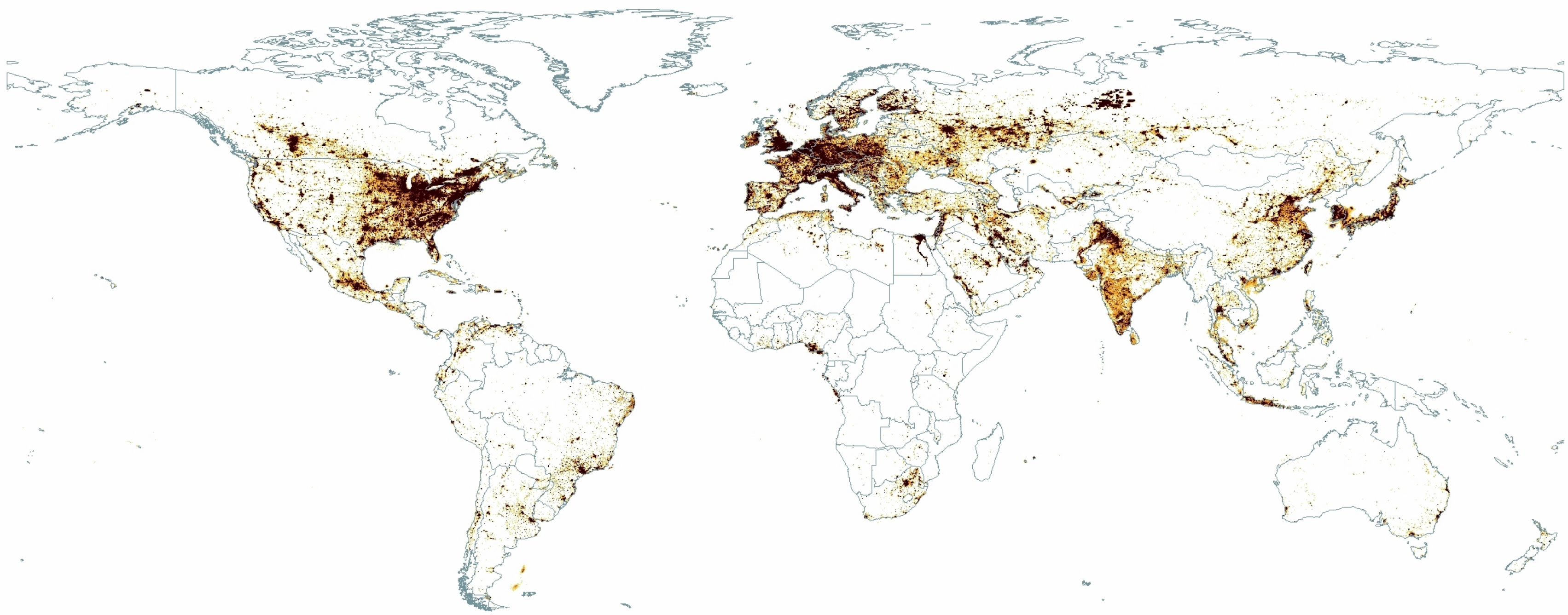
A country's level of industrialization explains a large portion of the global variation. South Africa has a similar population density but larger economy than neighboring Zimbabwe and a correspondingly higher light output. The difference across the 38th parallel on the Korean peninsula is particularly striking, revealing the impact of political institutions and economic development in a region with identical cultures and similar geography.

Numerous studies have validated the DMSP-OLS night lights images against measures of electric power consumption and gross domestic product (Elvidge et al. 1997*b*). More recently, scientists are using these data to model urbanization (Lo 2001, Small et al. 2005, Amaral et al. 2006) and the environmental impacts of fires and natural disasters (Fuller 2000, Kohiyama et al. 2004). The great virtue of these data for social science research is that they are unbiased, consistent, and complete.

Three technical limitations complicate the use of nighttime lights to estimate the extent and intensity of use of electrical infrastructure: saturation, blooming and low sensitivity. *Saturation* occurs because of the limited dynamic range of the satellite sensor. To accurately detect dimly lit areas, the sensors are calibrated with high gain on the photomultiplier tube. This results in small areas of saturation (i.e. cells with encoded brightness values of 63) in the centers of large cities and other brightly lit zones. This does not affect the analysis here since we are interested primarily on unlit cells. Blooming occurs when lights from an area appear to spill into neighboring areas resulting in an overglow. *Blooming* increases in the presence of nearby water sources and other sources that reflect nearby light into space. This means that nighttime light images tend to overestimate the extent of light coverage, especially around large cities and coastal settlements. Fortunately, this results only in a downward bias in the estimate of unlit populations; in addition, the effects of blooming are unlikely to be correlated at the country level with the political variables I am most interested in. The *limited sensitivity* of the DMSP sensors mean that not all dimly lit regions are detectable in satellite images. In theory, the DMSP sensors are capable of detecting radiances as low as $10^{-9}\mathrm{watts/cm^2/sr/}\mu\mathrm{m}$, and field checks have revealed that lights from U.S. towns as small as 120 people are detectable (Elvidge et al. 2001). However, even sparse cloud cover and minor atmospheric disturbances can cloak the lights from a small settlement. Moreover, because DMSP annual composite images are produced through image processing algorithms designed to remove ephemeral light sources like lightning and fires, it is possible that some of the most dimly lit (or irregularly lit) areas also get blacked out. The result is that the annual composite DMSP images do not unambiguously detect the electrification of small settlements. More research is required to understand the limits of light detection at the low end of the sensitivity spectrum. As a result, I propose a conservative strategy below which only identifies an area as unlit if the underlying population count exceeds a certain minimum threshold.

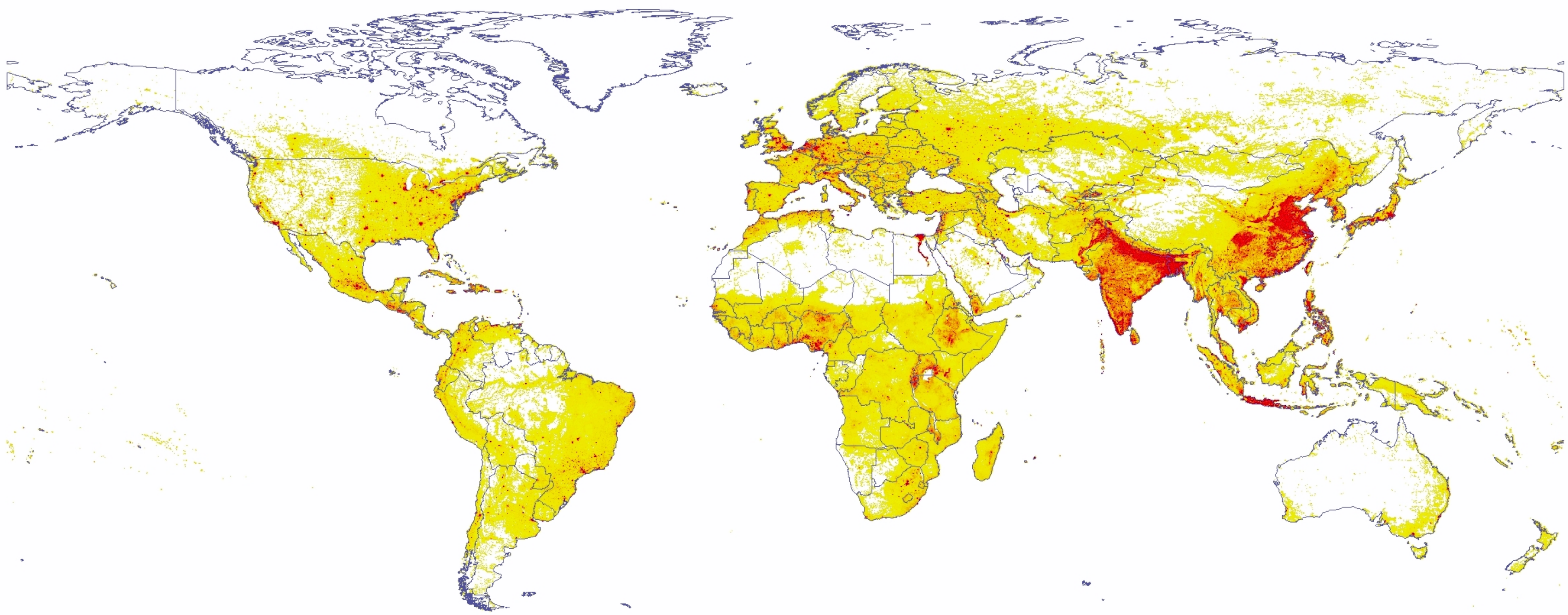
To identify populated regions, I draw on the LandScan 2006 population count map produced by the Oak Ridge National Laboratory (see Figure 4). This is the highest resolution population map currently available. Drawing on sub-national census data, population counts are apportioned onto a 30 arc-second grid using country-specific likelihood coefficients based on proximity to roads,

Figure 3: Nighttime lights of the world, 2003



Darker cells have higher light output.
Source: NOAA National Geophysical Data Center

Figure 4: Population of the world



Darker cells have higher population counts.
Source: Oak Ridge National Laboratory, LandScan 2006

slope, land cover, and other information.[9] The LandScan population maps have been thoroughly vetted and are widely used by the United Nations, World Health Organization, and Food and Agricultural Organization. LandScan 2006 uses satellite-based inputs to create their map including high resolution daytime imagery and land cover databases. It does not use night lights images, resulting in a data source that is fully independent of the DMSP-OLS night lights data.

A direct comparison of the raw LandScan and DMSP-OLS images reveals a very large number of populated cells with no light output. This is because even electrified areas might not generate a sufficient concentration of outdoor light if the population density is very low. Thus a direct comparison of these data sources does not yield a reliable estimate of unelectrified populations. To derive a more reliable estimate of unlit populations, we need to identify only those areas where we can reliably infer that lighting would be detectable *if it were present*. The approach used here matches the *most dimly* lit cells against *unlit* cells with similar population and economic characteristics. An unlit cell with the same population and economic characteristics as a dimly lit cell is inferred to be unelectrified. Practically speaking, I identify the median population count in the most dimly lit cells, and do this separately for each country of the world to allow for differences in economic and other fixed factors. I then sum the population in all unlit cells of a country whose population exceeds the country-specific threshold. Details are described in Appendix B.

To illustrate, I describe the method as applied to India. India is home to 1.1 billion people, making it the second most populous country in the world and the largest democracy. The DMSP satellite image of India for 2003 is composed of 4 million cells with a mean light output of 2.2 (4.9 excluding unlit cells) on the 0–63 scale. The median population count of the most dimly lit cells is 58, providing observational evidence that in India, outdoor lighting technology is detectable from space for cells with at least 58 people. Of the over 2 million unlit cells in which no light is detectable by satellite, about 690,000 have a population of at least 58. Summing the population counts across these unlit cells with at least 58 people yields a total estimate of about 275 million Indians living in unlit areas.[10]

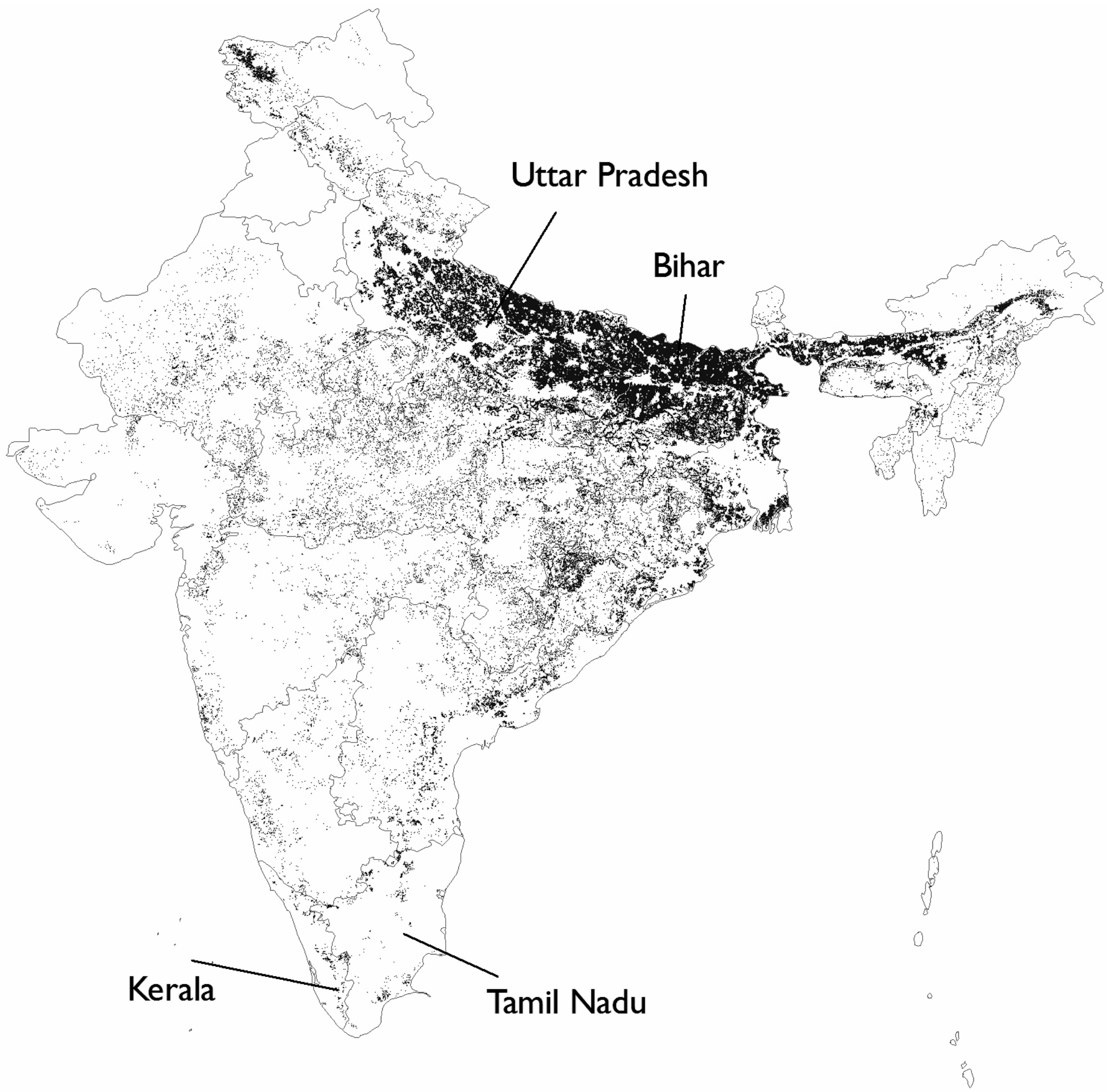
The distribution of unlit populations in India is plotted in Figure 5, with each dot indicating an unlit settlement and darker dots indicating higher population counts. The highest concentration of unlit populations are clearly visible on the northeast rim just south of Nepal. This area includes two of India's poorest states, Uttar Pradesh and Bihar. Note that even in these impoverished regions, urban cores are white, including the state capitals Lucknow and Patna, indicating the prevalence of electrical infrastructure in urban areas. In comparison, Kerala and Tamil Nadu on the southern tip of the Indian peninsula, have only a scattering of unelectrified communities. Indeed, India's Ministry of Power estimates that 42% of villages in Uttar Pradesh and 51% of Bihar lacked electricity in 2005. Meanwhile, the estimated rates for Kerala and Tamil Nadu were 3% and 0% respectively. In comparison, my satellite-derived method estimates that 37% of people in Uttar Pradesh live in unlit areas, 64% in Bihar, 3% in Kerala and 1% in Tamil Nadu.

Applying the method described above, I estimate that 1.4 billion people, or 22% of the global population, live in unlit areas of the world in 2003. Regional breakdowns are presented in Table 1 (see Appendix B for country estimates). This global estimate compares reasonably well with the

[9] LandScan was conceived as an effort to estimate the ambient or average population distribution over a 24-hour period. This differs from traditional population density estimates which measure residential settlement patterns, typically undercounting the presence of people in commercial centers and airports, for example. In practice, the "difference between ambient and resident population is not significant as the results are quite coarse in all available population density maps" (Salvatore et al. 2005, p. 16).

[10] In comparison, International Energy Agency (2006) estimates 440 million unelectrified homes in India, many of which are in electrified villages and towns. The population living in unelectrified villages, which my measure most closely resembles, has not been reported.

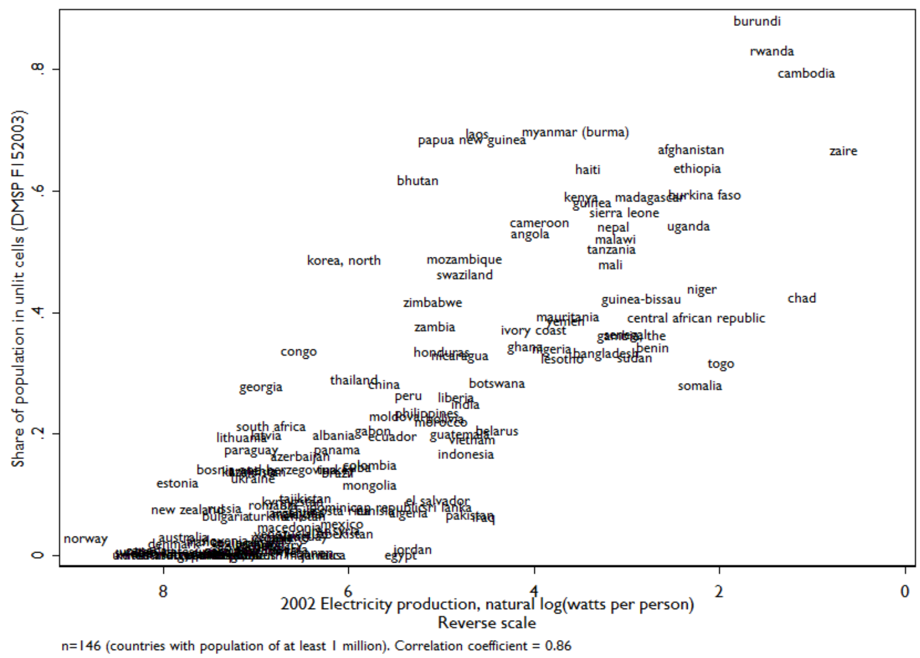
Figure 5: Estimated unlit populations in India, 2003



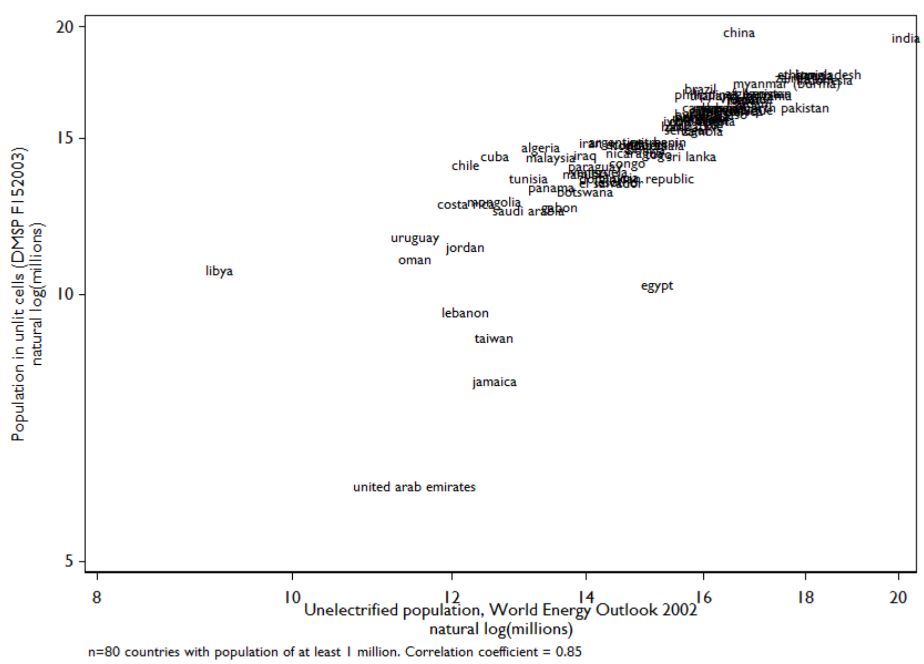
Darker areas have more people living in unlit areas. Each dot represents a populated 30 arc-second cell with no detectable light output. Estimated using DMSP F152003 and LandScan 2006 data.

Figure 6: Comparison of satellite and official estimates of electrification

(a) Comparison of satellite estimates of unlit population with official estimates of electricity production



(b) Comparison of satellite estimates of unlit population with official estimates of unelectrified population



Sources: DMSP-OLS F152003, LandScan 2006, 2007 update to Canning (1998), World Energy Outlook 2002

Table 1: Estimated unlit population from satellite images, 2003

Region	Total population (millions)	Unlit population (millions)	Unlit population (%)
Western Democracies and Japan	778	7	0.9%
North Africa and Middle East	414	34	8.1%
Eastern Europe	405	35	8.5%
Latin and Central America	546	71	12.9%
Asia	3,450	895	25.9%
Sub-Saharan Africa	746	349	46.8%
Other	88	2	2.1%
WORLD	6,427	1,391	21.6%

Source: Author calculations using DMSP-OLS F152003 and LandScan 2006.

IEA's projection of 1.6 billion people living without electricity, a number that includes the urban unelectrified (International Energy Agency 2006). It is also possible to compare the estimates of electrification derived from DMSP satellite imagery against sources of country-level data. Figure 6(a) contrasts satellite-derived estimates of the share of the unlit population against recent data on the electricity generating capacity of 149 countries. As expected, countries with lower levels of production capacity per person tend to be places where larger portions of the population live in unlit areas. These measures correlate at a level of 0.78. Figure 6(b) plots estimates of the total population living in unlit cells against International Energy Agency estimates of unelectrified populations derived from official government and UN statistics. Among the 85 countries for which IEA data exist, there are some notable outliers, including China. Many states in the Middle East are also poorly predicted (perhaps because of irregular lighting associated with oil production), though the general levels of unelectrification are low across the region. Still, the overall correlation of 0.89 is very high.[11]

These encouraging comparisons provide confidence that estimates of electrification derived from satellite images are highly plausible. Unlike the self-reported government data that are compiled in most widely used datasets, the accuracy of satellite-derived data are not affected by political and economic circumstances. These results provide an unbiased and objective estimate of unlit populations that are unlikely to be correlated with differences in the bureaucratic capacity of states, the consistency of record-keeping practices, or the honesty of state officials. Furthermore, the satellite images provide high-resolution information at the local and sub-national levels, offering opportunities for more detailed analysis not possible with official country data alone.

Some plausible objections exist that outdoor lights might not be an accurate indicator of publicly-funded electrification. If electrified areas do not have substantial outdoor lighting, they will be incorrectly classified as unelectrified by my procedure. While this is likely the case in some places, anecdotal reports and some studies show that electrification projects are often accompanied by public outdoor lighting. Attaching a light fixture to an existing electric utility pole is of low marginal cost but high potential benefit. For politicians seeking to win the favor of a community, public outdoor lights is a cost efficient way to demonstrate the success of an electrification project.

A different concern is that the presence of outdoor lighting might not be a reliable indicator of

[11] I show elsewhere that deviations between the satellite estimates and the government-reported IEA estimates are not random and are predicted by levels of income, population, corruption, and other measures. The presence of systematic measurement error suggests that regressions using government-reported data are likely to be biased and inconsistent.

government public goods provision if electricity is provided privately. In many parts of the developing world unconnected to the electric grid or where service provision is unreliable, privately-owned diesel and kerosene power generators provide electricity to those who can afford access. However, it is not likely that private generators are widely used to provide the kind of outdoor lighting detected by the DMSP sensor. Because outdoor lighting is expensive to provide but difficult to charge for, most entrepreneurs are unlikely to shine lights outdoors and into space. It is more likely that generators are used to power indoor lighting and other devices unlikely to be visible from space.

That said, neither of these two concerns are likely to lead to an incorrect inference about a beneficial effect of democratic institutions on electrification. Random measurement error on the dependent variable does not bias the slope coefficient but leads to larger standard errors, which makes it more difficult to find a statistically significant democracy effect. Systematic errors on the dependent variable will bias coefficient estimates towards zero when the errors are correlated with the predictor variables, which makes it more difficult to identify a democracy effect. However, there is no clear reason to believe that the concerns above should be systematically related to democracy or autocracy.

5 Democracy and Light

Most theories of public goods provision expect that democracies will provide higher levels of basic infrastructure like electrification than autocracies. If these theories are correct, we should find that more citizens enjoy the benefits of electrification in democratic regimes, and that the positive benefits of democracy should compound over time as elected leaders continue to seek votes through the provision of electrical infrastructure. Recent headlines highlight the political value of electrification to voters. In Liberia, President Ellen Johnson Sirleaf campaigned on a platform to restore order and stability to the civil war-ravaged country, including a promise to restore electricity to Monrovia, its capital city. Amidst celebratory crowds and cameras, President Sirleaf flipped a switch in July 2006, turning on streetlights that had been dark for 16 years since rebels knocked out Monrovia's power grid in 1990. When power outages swept across South Africa in late 2007, citizens directed their outrage towards their political leaders. The power crisis, considered the result of poor planning and government oversight, led the government to acknowledge that President Thabo Mbeki "has accepted that this government got its timing wrong" in what was called an extraordinary admission of failure.[12] The ongoing power crisis is likely to be a significant election issue for the African National Congress when Mbeki steps down in 2009.

If voters hold their politicians accountable for the provision of electrification, then democratic leaders should face higher incentives to provide electrification to their citizens than in autocracies. Using the satellite-based estimates of unlit populations described above, I evaluate the differences in the provision and distribution of rural electrification between democracies and autocracies. To assess the influence of democratic rule on rural electrification, I construct a measure of *Democratic history* which calculates the number of years from 1946 until 2002 that a country has been under democratic rule. I use the dichotomous coding of democracy from Cheibub & Gandhi (2004).[13] It is important to account for history since electrical infrastructure observed in 2003 is a stock measurement, accumulated through the flow of investments over years and decades. Looking only at the current level of democratization might yield incorrect inferences, since the extent of electrification in 2003 reflects the accumulation of a history of investment. That said, almost half

[12] *New York Times*, "Power Failures Outrage South Africa," 31 January 2008, quoting Alec Erwin, South Africa's Minister of Energy and Public Enterprises.

[13] I also compare my results using alternative democracy measures constructed from Polity2 data. See Appendix A.

of the countries in my data do not change regime type at any point during the post-war period: 52 countries have always been autocratic while 31 have stayed democratic.

Figure 7(a) shows electrification rates for 183 countries at all levels of democratic history (the sample size is limited only by the availability of regime-type data). Among sustained democracies, the provision of rural electrification is impressively uniform. In these 21 countries, only about 2 out of every 100 people live in unlit areas, with India appearing as a notable outlier. Among authoritarian regimes, the variance in electrification rates is much wider. In Rwanda and Burundi, more than three-quarters of the population live in unlit areas compared to less than 1% in Egypt and Jordan. Some of these differences are likely to be linked to oil wealth, but variation persists even among non-oil producing dictatorships.[14]

In the middle region of the figure lie almost half of the world's countries that have experienced some democratic and some autocratic rule since 1946. The pattern here remains consistent with the above: countries with a longer history of democratic rule have lower rates of unlit population. In addition, variation in electrification rates appears to decrease at all levels of democratic history.

Figure 7(b) shows the same scatter plot but using markers weighted by the population size of each country. Dominating the plot are the large markers associated with China and India. In stark contrast with the official electrification estimates reported at the beginning of the paper, the share of unlit populations are very similar for China and India using the satellite-based methodology. More research is required to investigate this discrepancy.

Partially obscured in both figures is the large number of countries that are effectively fully electrified: 43 countries have less than 1% of their population in unlit cells and 64 countries have less than 5% unelectrified. Many of these countries are wealthy (e.g. Norway, Saudi Arabia), have small territories (e.g. Jamaica, Lebanon), or both (e.g. Kuwait, Israel). The majority are democracies though about a quarter are autocracies.

To what extent does this pattern simply reflect the well-known differences in development between the (mostly) wealthy democratic west and the (mostly) autocratic developing world? Even comparing countries at similar levels of development, differences in democratic history appear to matter. Among the poorest half of the world's countries, with incomes below $4,589 per capita in 2002 (approximately the median observed value), those with no history of democratic rule had 39% of their populations in unlit areas compared with 34% for current democracies. A t-test shows that the difference is statistically significant at the $p=0.03$ level.

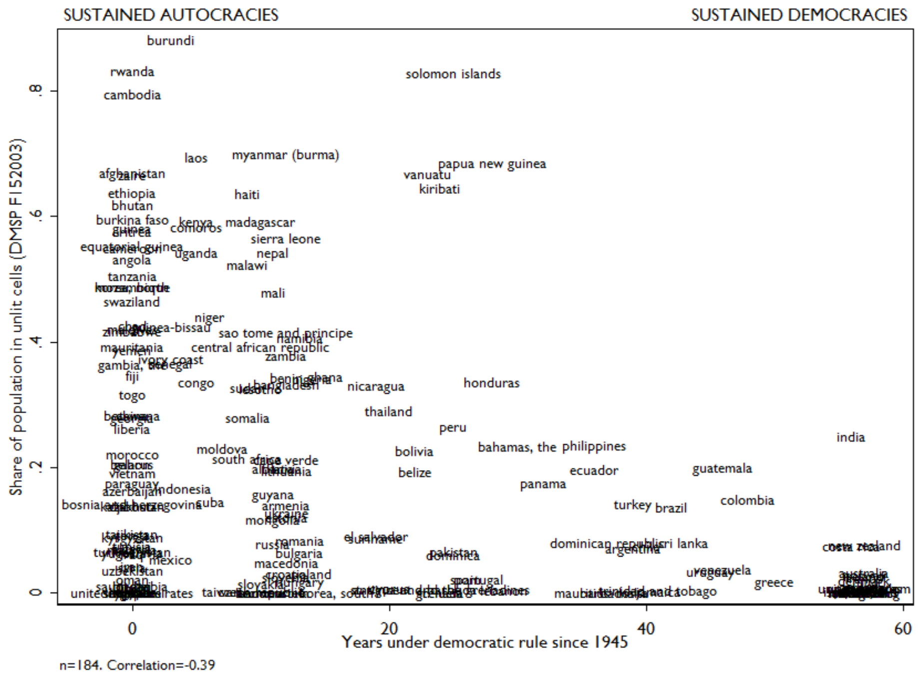
Many scholars have asserted that the choice of governments matter little in the poorest states. Przeworski, Alvarez, Cheibub & Limongi (2000, p. 163) write, "Poor countries cannot afford a strong state, and when the state is weak, the kind of regime matters little for everyday life." But satellite images of lit areas show otherwise. Among states with income levels in the bottom quartile — below $1,534 per capita — 44% of citizens living in democracies were in the dark compared to 52% in autocracies. For the average country in this group, this translates into nearly two million more people living without light in autocracies versus democracies. The difference is significant at the $p=0.02$ level.

These results suggest that even across different levels of development, more citizens enjoy electrification in democracies than in nondemocracies. Still, these highly suggestive results might be caused by other factors unrelated but correlated with democratic rule, like differences in geography or demography. I explore these concerns using regression analysis in the following sections.

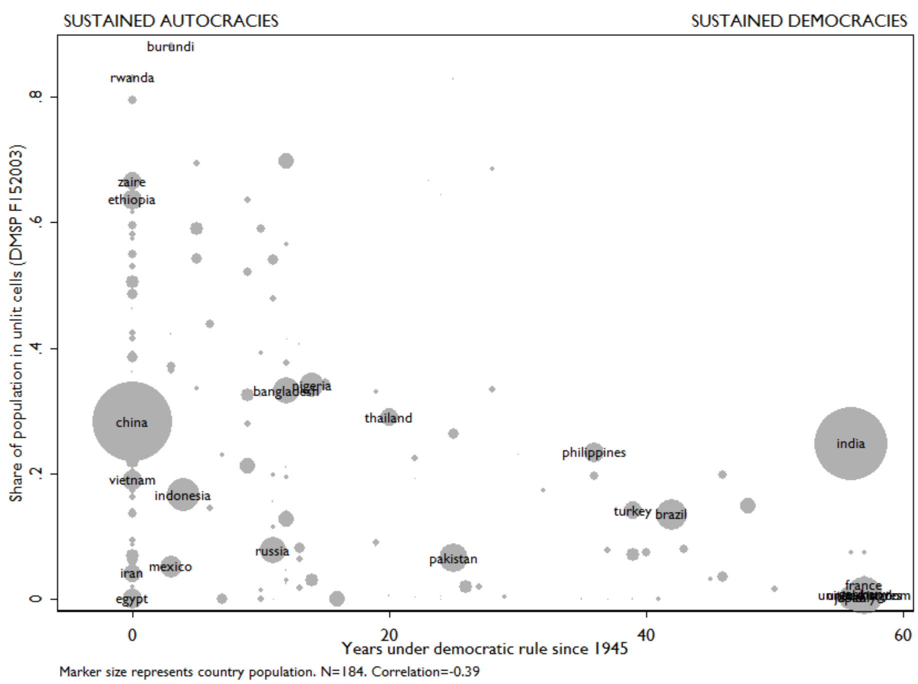
[14]Nighttime lights in oil producing countries is also likely to lead to an overestimate of the distribution of electrification: gas flares on oil wells and rigs generate high levels of outdoor light visible in the satellite images. Gas flaring is known to be particularly pronounced in Nigeria, Russia, Iran, Algeria, Mexico, Venezuela, and Indonesia.

Figure 7: Satellite estimates of unlit population by history of democratic rule

(a) Unlit population by history of democratic rule



(b) Markers weighted by population size



Sources: DMSP-OLS F152003, LandScan 2006, Cheibub & Gandhi (2004)

5.1 Cross-national analysis of unlit populations

To evaluate the effects of democracy on the provision of electrification, I conduct cross-national regressions on the proportion of a country's population living in unlit cells. Because my dependent variable is a proportion bounded at 0 and 1, ordinary-least squares regression is not appropriate since it will generate predicted values outside of this range. Instead, I use a fractional logit model following Papke & Wooldridge (1996) and Wooldridge (2002, p. 661). In the fractional logit model, the dependent variable, y is assumed to be a proportion generated by the logistic function,

$$E(y|\mathbf{x}) = exp(\mathbf{x}\beta)/[1 + exp(\mathbf{x}\beta)] \tag{1}$$

The β's are easily estimated in standard packages like R and Stata by specifying a generalized linear model with a binomial distribution and logit link function. The partial effects of a change in an independent variable in a fractional logit model are roughly comparable to the change based on the coefficients of an OLS model.[15]

The dependent variable is the proportion of a country's population living in unlit areas as of 2003, derived from nighttime DMSP satellite images and population estimates from the LandScan project. My key independent variable is a simple count of the number of years a country has been under democratic rule between 1946 and 2002. Among non-political variables, the most likely determinants of electrification are a country's level of industrialization and the distribution of its population. The level of industrialization is an indicator of a country's ability to afford the provision of electrification. Moreover, the more advanced an economy, the higher the demand for electrical infrastructure. I estimate the level of industrialization using the natural log of a country's *GDP PER CAPITA* in 2002. Data come from the Penn World Table 6.2 and are denominated in thousands of 2000 U.S. dollars. A country's *POPULATION DENSITY* will also affect the feasibility of electrification since sparsely populated countries must absorb higher per capita costs to electrify remote areas. I use the natural log of the population density, which is in people per km^2 and is computed from LandScan 2006 population numbers and World Development Indicators data on surface area. To account for differences in urbanization across countries, I also control for a country's *RURAL POPULATION*, calculated as the percent of the population living in rural areas in 2002 as defined by national governments and recorded in the World Development Indicators.

I include several other control variables. Violent civil wars and conflicts can quickly destroy infrastructure that might have taken years to build. As a result, countries who have suffered from a higher *NUMBER OF CIVIL ARMED CONFLICTS* might have lower levels of electrification. This variable, derived from the PRIO Armed Conflicts Dataset 3.0, counts the total number of internal conflicts with at least 25 battle-related deaths from 1946–2002. Many scholars have found a relationship between ethnic diversity and public goods provision. I include a measure of *ETHNOLINGUISTIC FRACTIONALIZATION* that comes from Fearon & Laitin (2003). The physical geography of a country might make it more difficult for a government to provide rural electrification. For example, the presence of rough and *MOUNTAINOUS TERRAIN* increases construction and maintenance costs for electrical infrastructure. This measure also comes from Fearon & Laitin (2003). Geography may also affect the underlying demand for electricity. Places at a higher *ABSOLUTE LATITUDE* will have more hours of darkness and colder temperatures. I use the latitude of a country's capital city as coded by Gleditsch (2003).

Access to natural resources like oil might affect the incentives of governments to electrify their rural populations, both by diverting state resources toward resource extraction activities and by

[15] An alternative is to use the log-odds transformation, $\log[y/(1-y)]$, as the dependent variable, since $\log[y/(1-y)]$ ranges over all real values while y is strictly bounded between 0 and 1. However, the log-odds transformation fails when y takes on the boundary values of 0 and 1 where the transformation is undefined.

Table 2: Fractional logit analysis of unlit populations

Dependent variable is share of country population in unlit areas, 2003

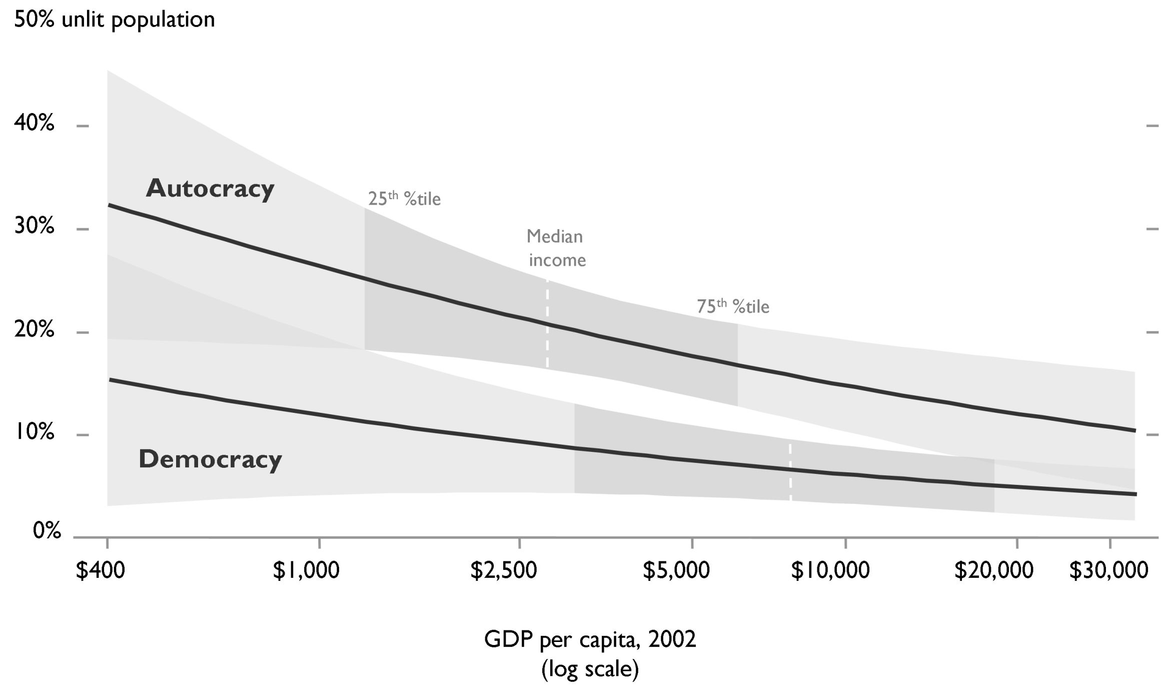
	ALL COUNTRIES		*EXCLUDING OECD*	*DEVELOPING COUNTRIES ONLY* (GDP/cap > $10,000)
	(1)	(2)	(3)	(4)
Democratic history, 1946–2002	-0.0355**	-0.0170**	-0.0176**	-0.0167**
	(0.0053)	(0.0053)	(0.0062)	(0.0065)
log (Population density), 2002		-0.1017	-0.0902	-0.0679
		(0.0619)	(0.0615)	(0.0635)
log (GDP/capita), 2002		-0.3206**	-0.2595*	-0.2419
		(0.1230)	(0.1203)	(0.1316)
Rural population (%), 2002		0.0215**	0.0210**	0.0243**
		(0.0053)	(0.0053)	(0.0058)
Absolute latitude of capital city		-0.0278**	-0.0274**	-0.0338**
		(0.0066)	(0.0070)	(0.0071)
Civil armed conflicts, 1946–2002		0.0195	0.0179	0.0164
		(0.0457)	(0.0456)	(0.0467)
Ethno-linguistic fractionalization		-0.1203	-0.1457	-0.1735
		(0.3283)	(0.3244)	(0.3321)
log (Mountainous terrain)		0.0753	0.0617	0.0934*
		(0.0467)	(0.0489)	(0.0473)
Oil production per capita, 2002		-0.0891*	-0.1214*	-0.0427
		(0.0416)	(0.0476)	(0.0524)
Constant	-0.8255**	1.5993	1.1714	0.7092
	(0.1175)	(1.1597)	(1.1395)	(1.2843)
Observations	184	147	119	107

Huber-White robust standard errors in parentheses. ** p-value $\leq$ .01, two-tailed test. * p-value $\leq$ .05, two-tailed test.

diminishing the accountability of governments towards their populations. Gas flaring associated with oil production also generates excess nighttime light output. I include a measure of *OIL PRODUCTION PER CAPITA* in barrels as recorded for 2002, derived from Humphreys (2005) and BP's *Statistical Review of World Energy 2007*. The distribution of these variables is summarized in Appendix A.

Table 2 presents fractional logit regression results to test the effects of democratic rule on unlit populations. I run all models using the Huber-White sandwich estimator to correct for heteroscedasticity. Model 1 shows the bivariate relationship between years of democratic rule and electrification. Since the dependent variable is the share of the population living in unlit areas, the democratic coefficient should have a negative sign, reducing the unlit population as seen here. Going from fully sustained autocratic rule to fully sustained democratic rule is linked with a 25% decrease in the population living in unlit areas. While this is a very large effect, it might be generated by other confounding factors not included in the model but correlated with democracy like country-level wealth. Moreover, we know from Figure 7 that since there is so much variance among autocracies, regime type alone is a relatively poor predictor of electrification levels absent any other information. What we would like to know is whether autocracies and democracies at similar levels of income and population distributions provide different levels of electrification. I account for these and other potential factors in the next model. Model 2 shows that the effect of democratic rule is substantial even after controlling for a wide range of country-level differences. Comparing two countries with

Figure 8: Predicted unlit population by regime type and income level



Note: Predicted values based on Table 2, Model 2 with bootstrapped 95% confidence intervals. Autocracy is a country with no history of democratic rule, while Democracy is a country with sustained democratic rule since 1945 (i.e. 57 years). All other variables are held at their mean or modal values. Darker regions show inter-quartile range of observed per capita income values in 2002 among autocracies and democracies.

mean levels of all variables except that one has been democratic over the entire post-World War II period and the other has stayed autocratic, the democratic state provides electrification to 10% more of their citizens than the dictatorship. This is sizeable, given that 29% of the population lived in the dark in the average autocracy. Put another way, in a typical autocracy with 35 million citizens, an alternate history of sustained democratic rule will have provided electrification for an additional 3.5 million more residents.

The population and income variables are highly significant. Wealthier countries have fewer people living in the dark: an increase of $1,000 in per capita income from the observed mean is associated with a 1.1% reduction in the share of the unlit population. The population density result has a negative sign as expected, suggesting that more densely populated countries are likely to have fewer people living in the dark. A country's war history and ethnic diversity do not predict electricity provision. Countries with more rugged terrain have more people in the dark, though the coefficient misses standard levels of significance. Finally, higher levels of oil production indicate the availability of energy resources for domestic use and are linked with more widespread electrification.

The effects of regime type and income are plotted in Figure 8, based on the equation in model 2. At every level of development, democracies are predicted to have a smaller proportion of their population in unlit areas than autocracies. The difference is statistically significant, except at very low levels of income (where there are few democracies) and high levels of autocracy (where there are few autocracies).

To what extent is the positive effect of democratic rule driven by the wealthy Western democracies? To evaluate this possibility, Model 3 excludes the 30 highly developed OECD nations and yields nearly identical results. Model 4 focuses the analysis on the developing world, excluding countries with per capita income greater than $10,000. The results are again nearly identical, suggesting that even poor and middle-income democracies provide electrification to more citizens than their autocratic counterparts. The results are also robust to alternative measures of democratic history. Drawing on codings from the Polity IV project, different measures of democratic rule yield coefficients that are consistent in size and significance to the results shown here (see Appendix Table 5 for results). Other model specifications were also examined, including a population weighted regression, inclusion of region fixed effects, and controlling for possible interaction effects. All models yield the same prediction that democracies provide lights to more of their population than autocracies (see Appendix Table 6 for results). Notably, an identical analysis (not shown here) using the IEA's electrification rates derived from government self-reports and third-party estimates reveals no democratic effect, demonstrating the potential perils of missing data and measurement error in standard cross-national analysis.

Taken together, these findings support the claim that electoral incentives induce higher public goods provision in democracies. Across a range of samples and model specifications, democratic leaders provide substantially higher levels of electrification than do autocrats, even after controlling for differences in wealth, population density, and other factors. Nevertheless, the results should be interpreted with some caution. Recent work has challenged the use of standard cross-sectional research methods in comparing democracies and dictatorships (Przeworski et al. 2000, Keefer 2005, Ross 2006). Since the causal factors that lead countries to democratize might also be correlated with the outcomes we seek to evaluate, inferences about the effects of democracy might be weakened by selection bias. Some of this concern is mitigated by my measure of democratic history, which takes period under democratic rule into account and not just the current level of democracy. However, it is still possible that the observed electrification level is not causally linked to democracy. For example, a country that transitions to democracy might already have high levels of electrification, and inferring that it was democracy that led to the provision of lighting would be incorrect. One way of mitigating this concern is to compare only the subsample of states that have not experienced a regime transition during the postwar period. Within this group, the average unlit population was 26% higher in the 51 fully sustained autocracies compared to the 17 sustained democracies (see also Appendix Table 6).

A far more robust evaluation of the effects of democracy could be identified if we could randomly assign a democratic "treatment" to a group of countries and compare their performance over time against a "control" group of otherwise similar autocratic countries. While such an ideal experiment could never be conducted, we can exploit the occurrence of a quasi-natural experiment that occurred after the fall of Communism across Eastern Europe and Central Asia in the early 1990s. I evaluate this question in the following section.

5.2 Democratic transitions in the former Soviet Bloc

The period of 1992 to 2003 for which nighttime satellite images are available captures what some have called the fourth wave of democratization: with the end of the Cold War and the downfall of Communism, rapid transitions to democracy occurred in many parts of the world (McFaul 2002, Doorenspleet 2005). Nowhere were these changes as sweeping and dramatic as across the former Soviet Bloc. As the Berlin Wall fell and the Soviet Union dissolved, a group of 28 states that had been united under Communist governments loyal to Moscow abandoned their governments. In the ensuing decade, many retained authoritarian rule but 12 transitioned to become democracies (see Table 3). The fall of Communism in a substantial group of countries with roughly similar political

Table 3: Difference-in-differences effect of democratic transitions in formerly Communist states, 1992–2003

	Treatment Group	Control Group
Proportion unlit, 1992	15.1%	15.5%
Proportion unlit, 2003	7.4%	12.2%
Difference	−7.7%	−3.3%
Treatment effect	−4.4%	

Note: According to McFaul (2002), the states that became democratic are Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Mongolia, Poland, Romania, Slovakia, and Slovenia. The autocratic states are Albania, Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Macedonia, Moldova, Russia, Serbia & Montenegro, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan. Bosnia & Herzegovina and Moldova are outliers and are excluded.

histories in roughly the same place and time provides a unique quasi-natural experiment to evaluate the effects of democratic transition on electrification. By assigning the 12 states that experienced a democratic transition to a "treatment group" and those that did not to a "control group", I evaluate a difference-in-differences model to assess the influence of becoming a democracy on lights provision from 1992 to 2003. While the satellite images from 1992 capture the status of electrification a few years later than the fall of the Berlin Wall, the estimates should provide a rough but reliable indicator of electrification at the end of Communist rule, especially since infrastructure provision is likely to change slowly over time.

In 1992, states in both the treatment and control groups had just under 9% of their populations living in unlit areas. Over the subsequent 12 year period, both groups experienced a decline in their unlit populations. But the decline in the states that became democratic was two and a half times higher than for those that stayed autocratic, 4.9% compared to 1.9%. Many fewer people live in the dark in the new democracies of Eastern Europe. However, this comparison does not account for other possible factors that might contribute to changes in electrification rates over time and might differ across the two groups. Nor can we tell whether the difference is statistically different from zero. Table 4 shows OLS regression coefficients addressing these concerns in a model of the form:

$$U_i = \beta_0 + \beta_1 Democracy_i + \beta_2 After_i + \beta_3 Democracy_i \times After_i + \gamma \mathbf{X_i} + \epsilon_i \qquad (2)$$

where U_i is the proportion of the population living in unlit areas in country i.[16] The dummy variable, $Democracy_i$, equals 1 for countries that became democratic during the period 1992 to 2003, and captures possible differences between the treatment and control groups prior to the democratic transition. The period dummy, $After_i$, captures aggregate factors that might affect both groups similarly over time. The difference-in-difference effect is captured by the interaction term, $Democracy_i \times After_i$, which measures the change in U_i associated with democratization.

A key assumption of the difference-in-differences estimator is that the treatment effect is random and not systematically related to other factors affecting the dependent variable, U_i. I attempt to account for potential factors affecting electrification rates aside from regime type by controlling for country characteristics, $\mathbf{X_i}$, including per capita income, population density, and other country variables previously discussed. Model 1, which includes no additional country controls, yields the same difference-in-differences estimate captured in the $Democracy \times After$ coefficient as in Table 3 (but now log transformed). The addition of country control variables in Models 2 improves the model fit but reduces the significance of the difference-in-differences estimate, just missing the standard 5% level of significance. Models 3 and 4 evaluate the same specification but using codings

[16] This variable is log transformed to achieve normality and scaled to ease interpretation, e.g. $\ln(prop\_unlit \times 100 + 1)$.

Table 4: OLS regression of democratic transition effects in formerly Communist states, 1992–2003

Dependent variable is natural log of share of country population in unlit areas				
	(1) McFaul transition	(2) McFaul transition	(3) Cheibub transition	(4) Polity transition
Democracy	-0.0711	-0.1804	-0.0021	-0.3754
	(0.2276)	(0.3081)	(0.3600)	(0.2624)
After	-0.2473*	-0.3275**	-0.3194*	-0.2108
	(0.1173)	(0.1167)	(0.1547)	(0.1034)
Democracy × After	-0.6061**	-0.4416^{+}	-0.3256	-0.6423**
	(0.2155)	(0.2213)	(0.2232)	(0.1979)
log (GDP/capita)		-0.4733*	-0.5865*	-0.5434**
		(0.1850)	(0.2161)	(0.1646)
log (Population density), 2002		-0.0955	-0.0391	-0.0634
		(0.1585)	(0.1510)	(0.1167)
Rural population (%), 2002		-0.0050	-0.0087	-0.0115
		(0.0145)	(0.0172)	(0.0132)
Absolute latitude of capital city		0.0011	-0.0027	0.0022
		(0.0239)	(0.0233)	(0.0199)
Ethno-linguistic fractionalization		0.1335	0.3717	-0.6631
		(0.7712)	(0.6874)	(0.6663)
log (Mountainous terrain)		-0.1433	-0.1331	-0.0406
		(0.1494)	(0.1592)	(0.1283)
Oil production per capita, 2002		-0.0130	0.0715	0.0173
		(0.1476)	(0.1649)	(0.0987)
Constant	2.6992**	4.6501*	4.6289*	4.9677**
	(0.1302)	(2.0071)	(2.1302)	(1.7512)
Number of countries	26	26	26	26
Observations	52	52	52	52
R-squared	0.24	0.37	0.33	0.49

Note: Two outliers excluded (Bosnia and Herzegovina and Moldova). Huber-White robust standard errors in parentheses. ** p-value $\leq$ .01, * p-value $\leq$ .05, $^{+}$ p-value $\leq$ .10, two-tailed tests.

of democratic transitions from Cheibub & Gandhi (2004) and the Polity IV project. The Cheibub dummy codings of regime type, which emphasize only the existence of competitive elections, does not yield a statistically significant coefficient on the difference-in-differences estimator, though it stays negative. The Polity coding, which identifies transitions from below to above the $+6$ Polity score threshold, generates a much stronger coefficient on the difference-in-differences estimator.

Given the relatively small number of countries in the observation sample and short period of time under observation, the theory that democratic transitions lead to increased public goods provision is at least partially supported. Overall, the observed change in electrification rates in the formerly Communist states suggest that democracies not only provide broader levels of electrification but that the positive effect of democratization is also visible over time.

6 Conclusion

This paper demonstrates that democracies provide electrification to many more of their citizens than autocracies. Drawing on new estimates of electrification whose reliability and validity are not sensitive to endogeneity with the political institutions we want to evaluate, I show a positive link between democratic rule and electrification that is robust to differences in development, demographics, and geography.

Future research will need to address several questions raised by the results and analysis presented in this paper. First, even if democracies provide public goods to more of their citizens than autocracies, how do we know whether these public goods are distributed more equitably or efficiently than in autocracies? Data limitations have made it impossible to evaluate distributional questions of this kind at a global scale. The comprehensive coverage of the night lights satellite images combined with their high resolution may provide a unique data source for the analysis of these important distributional issues. Second, if the provision of electrification is conditional on the electoral accountability of politicians, then differences in electoral rules should have an observable impact on the distribution of electrical infrastructure. States with proportional representation voting systems, for example, should have fewer pockets of unlit communities than states with majoritarian systems since small voting blocs are more likely to have electoral representation in PR systems (Lizzeri & Persico 2001, Milesi-Ferretti, Perotti & Rostagno 2002). Third, what explains the wide variance in electrification rates across autocracies? Do other institutions of accountability exist in autocracies (see e.g., Tsai 2007) that might induce some dictators to distribute electricity more broadly to their rural citizens (and perhaps even more than some democratic leaders)? Fourth, what explains the discrepancy between satellite-derived estimates of electrification and the official tallies reported in the most widely used cross-national datasets? Finally, what inferences can be drawn about whether electrification provision is related to the distribution of other basic public goods and services like water, education, and health? Seeking answers to these questions should extend the possible applications of satellite imagery for the analysis of state activities and other political phenomena.

References

Acemoglu, Daron & James A. Robinson. 2006. *economic origins of dictatorship and democracy*. New York: Cambridge University Press.

Alesina, Alberto, Reza Baqir & William Easterly. 1999. "Public goods and ethnic divisions." *Quarterly Journal of Economics* 114(4):1243–1284.

Amaral, Silvana et al. 2006. "DMSP/OLS night-time light imagery for urban population estimates in the Brazilian Amazon." *International Journal of Remote Sensing* 27(5):855–870.

Austen-Smith, David & Jeffrey Banks. 1988. "Elections, coalitions, and legislative outcomes." *American Political Science Review* 82(2):405–422.

Banerjee, Abhijit, Rohini Somanathan & Lakshmi Iyer. 2005. "History, social divisions and public goods in rural India." *Journal of the European Economic Association* 3(2–3):639–647.

Barnes, Douglas F. & Willem M. Floor. 1996. "Rural energy in developing countries: a challenge for economic development." *Annual Review of Energy and the Environment* 21:497–530.

Baron, David P. & John A. Ferejohn. 1989. "Bargaining in legislatures." *American Political Science Review* 83(4):1181–1206.

Bates, Robert. 1974. "Ethnic competition and modernization in contemporary Africa." *Comparative Political Studies* 6(4):457–484.

Besley, Timothy & Stephen Coate. 1998. "Sources of inefficiency in a representative democracy: A dynamic analysis." *American Economic Review* 88(1):139–156.

Besley, Timothy & Stephen Coate. 2003. "Centralized versus decentralized provision of local public goods: A political economy approach." *Journal of Public Economics* 87(12):2611–2637.

Besley, Timothy et al. 2004. "The politics of public good provision: Evidence from Indian local governments." *Journal of the European Economic Association* 2(2–3):416–26.

Boix, Carles & Daniel N. Posner. 1998. "Social capital: Explaining its origins and effects on government performance." *British Journal of Political Science* 28(04):686–693.

Bratton, Michael & Nicholas van de Walle. 1994. "Neopatrimonial regimes and political transitions in Africa." *World Politics* 46(4):453–489.

Bueno de Mesquita, Bruce et al. 2003. *Logic of political survival*. Cambridge, MA: MIT Press.

Canning, David. 1998. "A database of world stocks of infrastructure, 1950–95." *World Bank Economic Review* 12(3):529.

Casper, Gretchen & Claudiu Tufis. 2003. "Correlation Versus interchangeability: The limited robustness of empirical findings on democracy using highly correlated data sets." *Political Analysis* 11(2):196–203.

Chandra, Kanchan. 2004. *Why ethnic parties succeed*. Cambridge, UK; New York, NY: Cambridge University Press.

Cheibub, José A. & Jennifer Gandhi. 2004. "Classifying political regimes: A six-fold measure of democracies and dictatorships." Annual Meeting of the American Political Science Association, Chicago, September.

Collie, Melissa P. 1988. "Universalism and the parties in the US House of Representatives, 1921–80." *American Journal of Political Science* 32(4):865–883.

Diaz-Cayeros, Alberto, Beatriz Magaloni & Estévez. forthcoming. "Vote-buying, poverty and democracy: The politics of social programs in Mexico, 1989–2006." Unpublished manuscript.

Doorenspleet, Renske. 2005. *Democratic transitions: Exploring the structural sources of the fourth wave*. Boulder, CO: Lynne Rienner.

Easterly, William & Ross Levine. 1997. "Africa's growth tragedy: Policies and ethnic divisions." *Quarterly Journal of Economics* 112(4):1203–1250.

Elvidge, Christopher et al. 1997*a*. "Mapping city lights with nighttime data from the DMSP Operational Linescan System." *Photogrammetric Engineering & Remote Sensing* 63(6):727–734.

Elvidge, Christopher et al. 1997*b*. "Relation between satellite observed visible-near infrared emissions, population, economic activity, and power consumption." *International Journal of Remote Sensing* 18(6):1373–1379.

Elvidge, Christopher et al. 2001. "Night-time lights of the world: 1994–1995." *ISPRS Journal of Photogrammetry & Remote Sensing* 56:81–99.

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

Friedl, M. et al. 2002. "Global land cover mapping from MODIS algorithms and early results." *Remote Sensing of Environment* 83(1):287–302.

Fuller, D.O. 2000. "Comparison of NOAA-AVHRR and DMSP-OLS for operational fire monitoring in Kalimantan, Indonesia." *International Journal of Remote Sensing* 21(1):181–187.

Gandhi, Jennifer & Adam Przeworski. 2006. "Cooperation, cooptation, and rebellion under dictatorships." *Economics and Politics* 18(1):1–26.

Gleditsch, Kristian. 2003. "Distance between capital cities dataset." http://privatewww.essex.ac.uk/ ksg/data-5.html.

Gradstein, Mark. 1993. "Rent seeking and the provision of public goods." *Economic Journal* 103(420):1236–1243.

Groseclose, Timothy & James M. Snyder. 1996. "Buying supermajorities." *American Political Science Review* 90(2):303–315.

Guinier, Lani. 1994. *The tyranny of the majority: Fundamental fairness in representative democracy*. New York: Free Press.

Habyarimana, James et al. 2007. "Why does ethnic diversity undermine public goods provision?" *American Political Science Review* 101(4):709–725.

Humphreys, Macartan. 2005. "Natural resources, conflict, and conflict resolution: Uncovering the mechanisms." *Journal of Conflict Resolution* 49(4):508–537.

Imhoff, Mark L. et al. 1997. "A technique for using composite DMSP/OLS "city lights" satellite data to map urban area." *Remote Sensing of Environment* 61(3):361–370.

International Energy Agency. 2002. *World Energy Outlook 2002*. Paris, France: Organisation for Economic Cooperation and Development (OECD)/IEA.

International Energy Agency. 2006. *World Energy Outlook 2006*. Paris, France: Organisation for Economic Cooperation and Development (OECD)/IEA.

Keefer, Philip. 2005. Democratization and clientelism: why are young democracies badly governed? Working Paper Series No. 3594. World Bank. Washington, DC: World Bank.

Keefer, Phlip & Stuti Khemani. 2005. "Democracy, public expenditures, and the poor: Understanding political incentives for providing public services." *World Bank Research Observer* 20(1):1–27.

Kohiyama, M. et al. 2004. "Early damaged area estimation system using DMSP-OLS night-time imagery." *International Journal of Remote Sensing* 25(11):2015–2036.

Kromm, David E. 1970. "Soviet planning for increases in electric power production and capacity." *Transactions of the Kansas Academy of Science* 73(3):281–291.

Lake, David A. & Matt Baum. 2001. "The invisible hand of democracy: political control and the provision of public services." *Comparative Political Studies* 34(6):587–621.

Lee, Kuan Yew. 2000. *From third world to first: The Singapore story: 1965-2000*. New York: Harper Collins.

Lindert, Peter H. 2004. *Growing public: Social spending and economic growth since the eighteenth century*. New York: Cambridge University Press.

Lipset, Seymour Martin. 1959. "Some social requisites of democracy: Economic development and political legitimacy." *American Political Science Review* 53(1):69–105.

Lizzeri, A. & N. Persico. 2001. "The provision of public goods under alternative electoral incentives." *American Economic Review* 91(1):225–239.

Lo, C.P. 2001. "Modeling the population of China using DMSP operational linescan system nighttime data." *Photogrammetric engineering and remote sensing* 67(9):1037–1047.

McFaul, M. 2002. "The fourth wave of democracy and dictatorship: Noncooperative transitions in the postcommunist world." *World Politics* 54(2):212–244.

Meltzer, Allan H. & Scott F. Richard. 1981. "A rational theory of the size of government." *Journal of Political Economy* 89(5):914–927.

Miguel, Edward. 2004. "Tribe or nation? Nation-building and public goods in Kenya versus Tanzania." *World Politics* 56(3):327–362.

Milesi-Ferretti, Gian Maria, Roberto Perotti & Massimo Rostagno. 2002. "Electoral systems and public spending." *Quarterly Journal of Economics* 117(2):609–657.

Montalvo, Jos'e Garcia & Marta Reynal-Querol. 2005. "Ethnic diversity and economic development." *Journal of Development Economics* 76:293–323.

Nye, David E. 1992. *Electrifying America: Social meanings of a new technology, 1880–1940*. Cambridge, MA: MIT Press.

Pan, Jiahua et al. 2006. "Rural electrification in China 1950–2004: Historical processes and key driving forces." Program on Energy and Sustainable Development.

Pande, Rohini. 2003. "Can mandated political representation increase policy influence for disadvantaged minorities? Theory and evidence from India." *American Economic Review* 93(4):1132–1151.

Papke, Leslie E. & Jeffrey M. Wooldridge. 1996. "Econometric methods for fractional response variables with an application to 401 (k) plan participation rates." *Journal of Applied Econometrics* 11(6):619–632.

Persson, Torsten & Guido Tabellini. 2000. *Political economics: Explaining economic policy*. Cambridge, MA: MIT Press.

Persson, Torsten & Guido Tabellini. 2003. *Economic Effects of Constitutions*. Cambidge, MA: MIT Press.

Posner, Daniel N. 2004. "Measuring ethnic fractionalization in Africa." *American Journal of Political Science* 48(4):849–863.

Przeworski, A., M. Alvarez, J. Cheibub & F. Limongi. 2000. *Democracy and Development: Political Institutions and Material Well Being in the World*. New York: Cambridge University Press.

Rodriguez, E., C.S. Morris & J.E. Belz. 2006. "A Global Assessment of the SRTM Performance." *Photogrammetric Engineering and Remote Sensing* 72(3):249–260.

Ross, Michael L. 2006. "Is Democracy Good for the Poor?" *American Journal of Political Science* 50(4):860–874.

Salvatore, Mirella et al. 2005. Mapping global urban and rural population distributions. Environment and Natural Resources Working Paper 24, Food and Agriculture Organization of the United Nations. Rome: Food and Agriculture Organization of the United Nations.

Scheiner, Ethan. 2006. *Democracy without competition in Japan: Opposition failure in a one-party dominant state*. New York: Cambridge University Press.

Schmitter, Philippe C. & Terry L. Karl. 1991. "What democracy is...and is not." *Journal of Democracy* 2(3):75–88.

SHP News. 2004. "Small hydro power-based rural electrification in China." *SHP News* 21(Autumn):2–10.

Small, C. et al. 2005. "Spatial analysis of global urban extent from DMSP-OLS night lights." *Remote Sensing of Environment* 96(3–4):277–291.

Stokes, Susan C. 2005. "Perverse accountability: A formal model of machine politics with evidence from Argentina." *American Political Science Review* 99(03):315–325.

Tsai, Lily. 2007. "Solidary groups, informal accountability, and local public goods provision in rural China." *American Political Science Review* 101(02):355–372.

U.S. Census Bureau. 1975. *Historical statistics of the United States: Colonial times to 1970*. Washington, DC: U.S. Census Bureau.

Wantchekon, Leonard. 2003. "Clientelism and voting behavior: Evidence from a field experiment in Benin." *World Politics* 55(3):399–422.

Weingast, Barry R., Kenneth A. Shepsle & Christopher Johnsen. 1981. "The political economy of benefits and costs: A neoclassical approach to distributive politics." *Journal of Political Economy* 89(4):642–664.

Wilkinson, Steven I. 2006. "The politics of infrastructural spending in India." Background paper for Dancing with Giants: China, India, and the Global Economy. Institute for Policy Studies and the World Bank, Washington, DC. July.

Wittman, Donald. 1989. "Why democracies produce efficient results." *Journal of Political Economy* 97(6):1395–1424.

Wooldridge, Jeffrey M. 2002. *Econometric analysis of cross section and panel data*. Cambridge, MA: MIT Press.

World Bank. 2008. The welfare impact of rural electrification: A reassessment of the costs and benefits. Technical report Independent Evaluation Group (IEG). Washington, DC: World Bank.

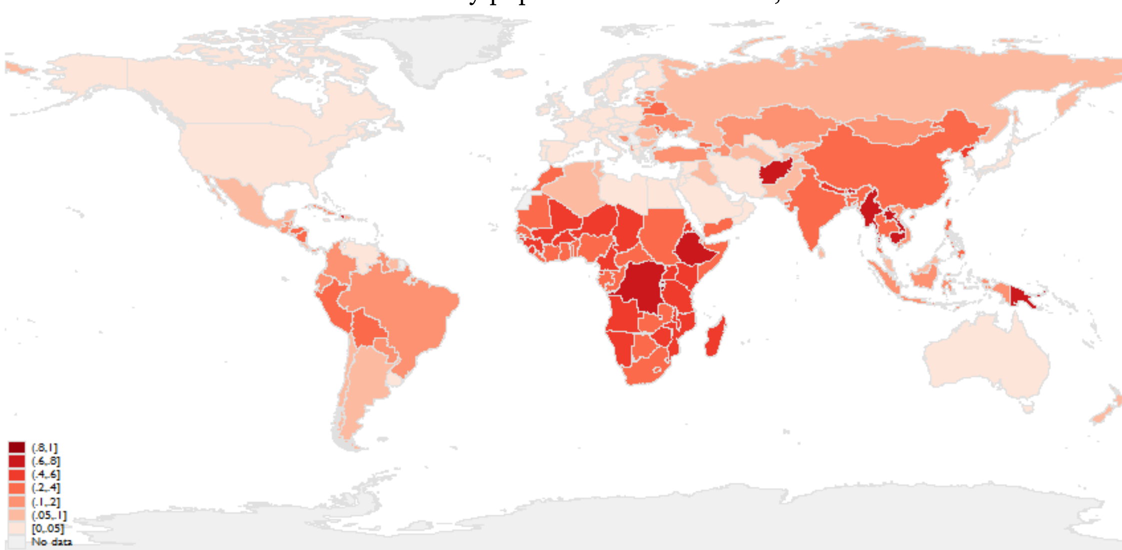
Appendix A: Descriptive Statistics and Robustness Checks

Descriptive statistics

Variable summary

Variable	Observations	Mean	Std. Dev.	Min	Max
Share of country population in unlit areas	184	0.21	0.23	0	0.88
Democratic history, 1946–2002	184	17.29	19.60	0	57
ln (GDP/capita), 2002	148	8.41	1.18	5.82	10.44
ln (Population density), 2002	184	6.43	1.44	2.62	11.57
Rural population (%), 2002	183	46.18	23.77	0	90.84
Absolute latitude of capital city	182	25.71	16.88	0	64
Civil armed conflicts, 1946–2002	148	1.34	1.68	0	11
Ethno-linguistic fractionalization	148	0.41	0.28	0.001	0.93
ln (Mountainous terrain)	148	2.15	1.42	0	4.42
Oil production per capita, 2002	148	1.63	5.95	0	43.42

Share of country population in unlit areas, 2003



Alternative measures of democratic history

The results presented in the paper are highly robust to alternative measures of democracy. Table 5 shows versions of the main model using several measures of democratic history derived from the Polity IV project. Each of these measures yields an almost identical result to the one presented in the paper, both in terms of the size and statistical significance of the coefficient on democratic history. [17]

- Years Polity>0: Number of years from 1946–2002 in which Polity score is positive (1946
- Years Polity≥6: Number of years in which Polity score surpasses Polity's recommended threshold for "democracy."
- Years with competitive elections: Number of years in which the chief executive is chosen through competitive elections involving at least two parties (Executive Recruitment Concept 8 in the Polity project's codings).
- Σ Polity: The sum of the annual Polity scores (from -10 to $+10$), scaled to a 0–100 score.

Alternative model specifications

Table 6 evaluates the robustness of the main results to different model specifications. Model 1 includes only the sample of sustained democracies and autocracies to obviate any concern that the current level of electrification might be a result of progress under previous regime types. The size and sign of the democratic history coefficient remains similar to the results for the full country sample. Even given the much smaller sample size, it is significant at the 0.07 level.

Model 2 runs a population weighted regression to see whether the cross-sectional results might be driven by a handful of small countries. The largest country in my sample (China) has a population three orders of magnitude larger than the smallest (Trinidad and Tobago). Weighting each observation by its population size reduces the size and significance of the democratic history variable (p=0.09), though the sign remains negative as before. Model 3 adds controls for region fixed effects. Even controlling for unmeasured regional differences, the effect of democracy remains consistent and strong. Model 4 explores the inclusion of interaction effects. For example, it might be that democracies are better able to translate economic wealth into public goods provision. To ease the interpretation of interactions between two continuous variables, I center the democratic history, per capita income, and population density variables. While the interaction effects between democratic history and income; democratic history and population density; and income and population density are all significant, the independent effect of democratic rule remains as strong as before. These results are nearly identical for the reduced sample that excludes the 30 OECD countries (models 5–7).

[17] The other widely used set of democracy indicators comes from Freedom House. Unfortunately, these measures are availably only back to 1973, too recent to evaluate the effects of democratic history over decades as I do here. Given the high correlation that has been observed between the Freedom House and Polity measures (Casper & Tufis 2003), I do not expect the choice of indicators to yield substantive differences to my results.

Table 5: Fractional logit analysis of unlit populations using alternative democracy measures

Dependent variable is share of country population in unlit areas, 2003

ALL COUNTRIES	(1) Years Polity>0	(2) Years Polity≥6	(3) Years with competitive elections	(4) Σ Polity
Democratic history, 1946–2002	-0.0142*	-0.0162**	-0.0150**	-0.0193**
	(0.0056)	(0.0059)	(0.0057)	(0.0068)
ln (GDP/capita), 2002	-0.3214*	-0.3407**	-0.3289**	-0.3020*
	(0.1292)	(0.1282)	(0.1272)	(0.1282)
ln (Population density), 2002	-0.1057	-0.1217	-0.1051	-0.1114
	(0.0643)	(0.0646)	(0.0646)	(0.0647)
Rural population (%), 2002	0.0220**	0.0230**	0.0223**	0.0221**
	(0.0052)	(0.0053)	(0.0053)	(0.0053)
Absolute latitude of capital city	-0.0273**	-0.0252**	-0.0266**	-0.0272**
	(0.0065)	(0.0064)	(0.0062)	(0.0064)
Civil armed conflicts, 1946–2002	0.0210	0.0284	0.0224	0.0214
	(0.0439)	(0.0456)	(0.0449)	(0.0448)
Ethno-linguistic fractionalization	-0.0461	-0.1336	-0.0635	-0.0779
	(0.3327)	(0.3273)	(0.3290)	(0.3325)
ln (Mountainous terrain)	0.0630	0.0570	0.0589	0.0618
	(0.0475)	(0.0471)	(0.0469)	(0.0472)
Oil production per capita, 2002	-0.0894*	-0.0794*	-0.0829*	-0.0898*
	(0.0424)	(0.0393)	(0.0400)	(0.0413)
Constant	1.5935	1.7133	1.5888	1.4860
	(1.1844)	(1.1889)	(1.1783)	(1.1769)
Observations	147	147	147	147

EXCLUDING OECD	(5) Years Polity>0	(6) Years Polity>6	(7) Years with competitive elections	(8) Σ Polity
Democratic history, 1946–2002	-0.0153*	-0.0169*	-0.0150*	-0.0210*
	(0.0062)	(0.0073)	(0.0065)	(0.0082)
ln (GDP/capita), 2002	-0.2434	-0.2782*	-0.2672*	-0.2323
	(0.1254)	(0.1250)	(0.1240)	(0.1245)
ln (Population density), 2002	-0.0944	-0.1119	-0.0940	-0.0999
	(0.0636)	(0.0644)	(0.0642)	(0.0645)
Rural population (%), 2002	0.0215**	0.0228**	0.0218**	0.0217**
	(0.0052)	(0.0052)	(0.0052)	(0.0052)
Absolute latitude of capital city	-0.0269**	-0.0247**	-0.0259**	-0.0271**
	(0.0067)	(0.0067)	(0.0065)	(0.0068)
Civil armed conflicts, 1946–2002	0.0199	0.0276	0.0202	0.0207
	(0.0440)	(0.0462)	(0.0449)	(0.0452)
Ethno-linguistic fractionalization	-0.0675	-0.1651	-0.0864	-0.1037
	(0.3271)	(0.3248)	(0.3243)	(0.3284)
ln (Mountainous terrain)	0.0454	0.0400	0.0433	0.0453
	(0.0491)	(0.0488)	(0.0484)	(0.0488)
Oil production per capita, 2002	-0.1247**	-0.1101*	-0.1144*	-0.1232**
	(0.0483)	(0.0456)	(0.0466)	(0.0463)
Constant	1.0475	1.2719	1.1442	0.9991
	(1.1533)	(1.1627)	(1.1487)	(1.1468)
Observations	119	119	119	119

Huber-White robust standard errors in parentheses. ** p-value ≤ .01, two-tailed test. * p-value ≤ .05, two-tailed test.

Table 6: Fractional logit analysis of unlit populations: alternative model specifications

Dependent variable is share of country population in unlit areas, 2003

	ALL COUNTRIES				*EXCLUDING OECD*		
	Sustained Autocs & Democs only	Population Weighted	Region Fixed Effects	Inter-actions	Population Weighted	Region Fixed Effects	Inter-actions
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Democ. hist., 1946–02	-0.0164	-0.0096	-0.0189**	-0.0128*	-0.0072	-0.0234**	-0.0111*
	(0.0092)	(0.0057)	(0.0069)	(0.0050)	(0.0064)	(0.0075)	(0.0055)
ln (GDP/capita), 2002	-0.2999	-0.6523**	-0.3060**	-0.3380*	-0.5593**	-0.2507*	-0.3148*
	(0.2442)	(0.1732)	(0.1044)	(0.1381)	(0.1642)	(0.1016)	(0.1392)
ln (Pop. density), 2002	-0.0927	-0.1477	-0.0690	-0.2166**	-0.1416	-0.0476	-0.1980*
	(0.0902)	(0.0814)	(0.0665)	(0.0720)	(0.0776)	(0.0685)	(0.0773)
Rural pop. (%), 2002	0.0234*	0.0149*	0.0175**	0.0209**	0.0139*	0.0161**	0.0219**
	(0.0115)	(0.0069)	(0.0055)	(0.0050)	(0.0066)	(0.0055)	(0.0050)
Abs. latitude of capital	-0.0356**	-0.0160	-0.0135	-0.0268**	-0.0157	-0.0142	-0.0258**
	(0.0120)	(0.0083)	(0.0098)	(0.0061)	(0.0087)	(0.0102)	(0.0064)
Civil conflicts, 1946–02	-0.0146	0.0826	0.0081	0.0389	0.0605	0.0090	0.0485
	(0.0782)	(0.0440)	(0.0450)	(0.0379)	(0.0516)	(0.0467)	(0.0403)
Ethno-ling. frac.	-0.1945	-0.7783*	-0.2243	-0.1783	-0.6977	-0.2747	-0.1359
	(0.5267)	(0.3841)	(0.3536)	(0.2873)	(0.3714)	(0.3508)	(0.2909)
ln (Mtns. terrain)	0.0447	0.0818	0.0983	0.0510	0.0774	0.0900	0.0292
	(0.0939)	(0.0722)	(0.0513)	(0.0444)	(0.0760)	(0.0511)	(0.0477)
Oil prod/capita, 2002	-0.0696	-0.2319*	-0.0466	-0.1253**	-0.2526**	-0.0669	-0.1430**
	(0.0388)	(0.0968)	(0.0334)	(0.0429)	(0.0919)	(0.0353)	(0.0415)
Latin America and Carribean			0.9803*			1.2942**	
			(0.4376)			(0.4456)	
Eastern Europe and fmr. Soviet Union			0.4041			0.6912	
			(0.4479)			(0.3799)	
Asia			1.1571*			1.4571**	
			(0.4729)			(0.3994)	
Sub-Saharan Africa			1.1662*			1.4545**	
			(0.5252)			(0.4116)	
North Africa and Middle East			-0.1133				
			(0.5438)				
Democ. history × ln(GDP/capita)				-0.0103*			-0.0062
				(0.0044)			(0.0060)
Democ. history × ln(Pop. dens)				-0.0028			-0.0068
				(0.0038)			(0.0046)
ln(GDP/capita) × ln(Pop. dens)				-0.2494**			-0.2708**
				(0.0490)			(0.0536)
Constant	1.5400	4.7575**	0.3228	-1.7336**	4.0866**	-0.3201	-1.7605**
	(2.5572)	(1.4080)	(1.2991)	(0.3530)	(1.2777)	(1.1397)	(0.3836)
Observations	67	147	147	147	119	119	119

Huber-White robust standard errors in parentheses. ** p-value ≤ .01, two-tailed test. * p-value ≤ .05, two-tailed test.

Appendix B: Calculation of Unlit Populations

Nighttime lights from the DMSP-OLS

Since the early 1970s, the United States Air Force has operated the Defense Meteorological Satellite Program. Onboard each of these satellites, the Operational Linescan System (OLS) has a highly sensitive low-light imaging capability. While its original purpose was to detect clouds using moonlight, it also is able to detect lights from human settlements, fires, gas flares, heavily lit fishing boats, lightning, and the aurora.

The DMSP-OLS orbits the earth around its polar axis 14 times a day, capturing a 3000 km wide swath between approximately 20:00 and 21:30 local time for most of the globe. The low-light sensing capabilities of the OLS permit the detection of nighttime radiances down to $10^{-9}\mathrm{W/cm^2/sr/\mu m}$.[18] Early images were kept on film strips. Since 1992, images began to be digitally processed and archived at the NOAA National Geophysical Data Center. The NGDC has produced a global "stable lights" image for each year from 1992 to 2003 using all cloud-free DMSP-OLS smooth resolution data during a given calendar year. The "stable lights" product shows lights from cities, towns, and other sites with persistent lighting, including gas flares. Ephemeral events, such as fires and lightning are discarded. Background noise is identified and replaced with values of zero. Each pixel with data is assigned a digital number on a 2^6 scale, with values ranging from 1-63. Dark cells are coded 0.

LandScan population map

Since 1998, the LandScan project at the Oak Ridge National Laboratory has been working to create the highest resolution map of population distributions around the world. Drawing on sub-national census data, population counts are apportioned onto a 30 arc-second grid using country-specific likelihood coefficients based on proximity to roads, slope, land cover, and other information. Newer versions have been released periodically, reflecting improvements in methodology as well as improvements in underlying data sources. As such, it is not possible to evaluate pixel-by-pixel changes over time using earlier versions of their maps. Current LandScan products rely on satellite data from various sources including NASA MODIS land cover (Friedl et al. 2002), topographic data from the Shuttle Radar Topography Mission (Rodriguez, Morris & Belz 2006), imagery from Ikonos and Quickbird, and the high resolution Controlled Image Base (CIB) from the U.S. National Geospatial Intelligence Agency (NGA). The LandScan maps do not use night lights images, resulting in a data source that is fully independent of the DMSP-OLS night lights data.

Calculating unlit populations

To calculate the proportion of a country's population living in unlit areas, I compare the annual DMSP-OLS composite image against the LandScan 2006 population map. Both raster images are geo-rectified using the World Geodetic System 1984 geographic coordinate system and are mapped onto a 30 arc-second grid (approximately 1km^2 at the Equator). The images are clipped at the +65 and -65 circles since DMSP-OLS does not generate reliable light estimates at the poles. The two maps have no data sources in common, allowing for a direct cell-by-cell comparison of light output and population counts across the globe. However, given the limited sensitivity of the DMSP-OLS sensor, it is unlikely that all dark cells are unelectrified or lack outdoor lights. It may be that lights are too dispersed to be detected by sensor.

To derive an accurate estimate of unlit populations, we need to identify only those areas where we can reliably infer that lighting would be detectable *if it were present*. One way of approaching this is to do a paired comparison matching the *most dimly* lit cell against *unlit* cells with similar population and economic characteristics. An unlit cell with the same population and economic characteristics as a dimly lit cell is inferred to be unelectrified. Given that the DMSP-OLS sensor detects a minimal level of lighting in cells with these baseline population and economic characteristics, we infer that otherwise similar cells but with no detectable lighting are unelectrified.

[18]Data are collected in two resolution modes onboard the OLS. At full resolution, data is referred to as "fine" with a nominal spatial resolution of 0.5 km. On-board averaging of 5 by 5 blocks of fine data produces smoothed data with a nominal spatial resolution of 2.7 km. Most data are provided in the smooth spatial resolution mode.

Two possibilities were explored to identify these baseline characteristics. The first approach identifies country-specific minimum population density threshold. The second uses a single population density threshold globally. To calculate country-specific thresholds, we want to identify a minimum population threshold above which we can reliably assume that the lack of visible nighttime light output indicates a lack of electrification and outdoor lights. To do so, we calculate a country-specific minimum lit threshold which identifies a lower bound for population count per cell to use in identifying unlit but populated cells. We look at the population distribution across a country's most dimly lit cells as recorded in the DMSP-OLS annual composite image. This provides observational evidence that outdoor lighting technology is detectable from space for cells with at least this population count. The country specific threshold is set to equal the median population count observed in the most dimly lit populated cells.

In India, for example, the median population count of the most dimly lit cells is 58 (excluding unpopulated cells), providing strong evidence that in India, outdoor lighting technology is detectable from space for cells with at least 58 people. Dark unlit areas with cell populations of at least 58 are likely to be unlit and not simply lit but invisible. To identify the total unlit population of India, I sum the total population living in unlit cells with at least 58 people. This generates an unlit population estimate of 275.1 million in India out of a total population of 1.1 billion. Of the 1.4 million cells that comprise China, 160,290 are dimly lit. Within these dimly lit cells, half have a population count lower than 54. Setting this as the minimum population threshold for China, I then sum the population of all dark cells with at least 54 people, yielding an unlit population estimate of 365.4 million in China out of a total population of 1.3 billion. The quantile cutoffs for the US are 1,4,9,700 in 28,874 dimly lit cells (out of 1.4 million cells). The estimate of unlit population based on cells with population greater than 4 is 189,194.

A similar procedure was adopted but using a single minimum threshold for all countries, based on the median population in the most dimly lit cells across the entire globe. Using this threshold of 28 yielded slightly different results, generally providing lower unlit population estimates in many of the least lit countries. By comparison, the estimates for unlit populations using this method are 250 million, 342 million, and 112,000 in India, China, and the US respectively. The two sets of estimates produce a Spearman rank-order correlation of 0.98 and yield similar results in most of the regressions.

Satellite-derived estimates of unlit populations, 2003

Derived from analysis of night-lights imagery from DMSP-OLS 2003 and population data from LandScan 2006.

Rank	Country	Proportion Unlit	Unlit Population (10^6)	Total Population (10^6)
1	Burundi	88.0%	7,204.9	8,185.2
2	Rwanda	83.0%	8,004.2	9,641.6
3	Cambodia	79.4%	11,057.7	13,923.9
4	Myanmar (Burma)	69.8%	32,113.2	45,999.3
5	Laos	69.4%	4,416.8	6,366.8
6	Papua New Guinea	68.4%	3,466.4	5,064.2
7	Afghanistan	66.9%	20,783.2	31,081.0
8	Zaire	66.6%	41,511.2	62,354.9
9	Ethiopia	63.7%	47,606.2	74,787.4
10	Haiti	63.6%	5,047.9	7,940.9
11	Burkina Faso	59.4%	8,263.3	13,901.8
12	Madagascar	59.1%	11,047.5	18,701.8
13	Kenya	59.0%	20,799.4	35,243.2
14	Guinea	58.1%	5,645.2	9,723.1
15	Eritrea	57.4%	2,726.5	4,746.9
16	Sierra Leone	56.5%	3,327.4	5,890.6
17	Cameroon	54.9%	9,628.1	17,540.8
18	Uganda	54.2%	15,896.9	29,336.9
19	Nepal	54.1%	15,467.9	28,611.1
20	Angola	53.0%	6,345.2	11,962.9
21	Malawi	52.1%	6,927.6	13,289.0
22	Tanzania	50.5%	18,493.8	36,650.3
23	Mozambique	48.7%	9,865.9	20,250.9
24	Korea, North	48.6%	11,089.3	22,806.7

continued...

Rank	Country	Proportion Unlit	Unlit Population (10^6)	Total Population (10^6)
25	Mali	47.8%	5,592.3	11,697.6
26	Swaziland	46.3%	526.1	1,136.3
27	Niger	43.8%	5,480.7	12,506.7
28	Chad	42.4%	4,239.2	9,987.0
29	Guinea-Bissau	42.2%	497.6	1,178.1
30	Zimbabwe	41.6%	5,076.9	12,204.0
31	Namibia	40.6%	831.6	2,050.6
32	Mauritania	39.2%	1,248.2	3,183.2
33	Central African Republic	39.1%	1,661.3	4,244.2
34	Yemen	38.6%	8,168.8	21,165.9
35	Zambia	37.7%	4,272.3	11,335.4
36	Ivory Coast	37.2%	6,312.7	16,980.2
37	Senegal	36.4%	4,347.4	11,932.3
38	Gambia, The	36.2%	569.1	1,570.3
39	Ghana	34.3%	7,518.9	21,924.6
40	Benin	34.1%	2,714.2	7,950.6
41	Nigeria	34.1%	44,650.9	131,092.0
42	Congo	33.6%	1,260.6	3,756.3
43	Honduras	33.5%	2,391.7	7,143.2
44	Bangladesh	33.2%	48,036.0	144,690.0
45	Nicaragua	33.0%	1,820.1	5,517.9
46	Sudan	32.5%	13,400.0	41,220.4
47	Lesotho	32.4%	648.8	2,003.7
48	Togo	31.6%	1,751.0	5,544.5
49	Thailand	29.0%	18,607.9	64,221.1
50	Botswana	28.3%	453.9	1,605.9
51	China	28.2%	367,000.0	1,300,810.0
52	Somalia	27.9%	2,462.2	8,819.2
53	Georgia	27.8%	1,253.7	4,515.3
54	Peru	26.4%	7,452.0	28,271.6
55	Liberia	26.0%	685.4	2,635.4
56	India	24.8%	275,000.0	1,107,750.0
57	Philippines	23.4%	19,871.7	84,894.4
58	Moldova	22.9%	959.3	4,184.8
59	Bolivia	22.5%	2,016.0	8,954.9
60	Morocco	22.0%	7,217.9	32,860.1
61	South Africa	21.3%	9,369.1	44,014.8
62	Gabon	20.4%	272.5	1,334.2
63	Belarus	20.4%	1,991.4	9,757.5
64	Guatemala	19.9%	2,473.1	12,441.8
65	Albania	19.8%	703.5	3,558.6
66	Latvia	19.7%	441.7	2,243.0
67	Ecuador	19.6%	2,525.3	12,904.2
68	Lithuania	19.4%	877.1	4,513.0
69	Vietnam	19.0%	15,704.5	82,869.0
70	Paraguay	17.4%	1,128.8	6,504.6
71	Panama	17.3%	529.8	3,056.2
72	Indonesia	16.6%	36,816.8	221,867.0
73	Azerbaijan	16.3%	1,284.9	7,901.3
74	Colombia	14.8%	6,409.1	43,320.9
75	Cuba	14.5%	1,571.5	10,840.3
76	Bosnia And Herzegovina	14.1%	636.0	4,496.1
77	Turkey	14.1%	9,716.5	68,851.7
78	Armenia	13.9%	412.2	2,975.5
79	Kazakhstan	13.7%	2,099.0	15,327.7
80	Brazil	13.5%	24,892.3	184,226.0
81	Ukraine	12.7%	5,932.6	46,674.2
82	Estonia	12.0%	156.1	1,300.7
83	Mongolia	11.6%	327.2	2,826.4
84	Tajikistan	9.3%	649.4	6,953.3
85	El Salvador	9.0%	608.0	6,787.1
86	Kyrgyzstan	8.8%	448.8	5,127.5
87	Romania	8.2%	1,827.8	22,343.6
88	Sri Lanka	7.9%	1,581.9	19,985.4

continued. . .

Rank	Country	Proportion Unlit	Unlit Population (10^6)	Total Population (10^6)
89	Dominican Republic	7.8%	712.6	9,099.3
90	Russia	7.7%	10,864.4	140,892.0
91	New Zealand	7.5%	275.6	3,684.7
92	Tunisia	7.4%	719.7	9,707.9
93	Chile	7.4%	1,176.4	15,869.6
94	Costa Rica	7.4%	301.5	4,072.2
95	Argentina	7.0%	2,788.0	39,606.7
96	Algeria	6.9%	2,262.0	32,681.1
97	Malaysia	6.8%	1,528.9	22,366.3
98	Pakistan	6.5%	10,822.7	165,600.0
99	Turkmenistan	6.4%	324.5	5,050.9
100	Bulgaria	6.4%	467.4	7,320.4
101	Yugoslavia	6.4%	689.3	10,798.4
102	Iraq	6.2%	1,655.1	26,780.1
103	Mexico	5.2%	5,529.6	106,765.0
104	Macedonia	4.6%	95.0	2,054.1
105	Iran	4.1%	2,676.2	64,796.7
106	Syria	4.0%	740.1	18,533.5
107	Venezuela	3.6%	897.9	25,099.8
108	Uzbekistan	3.5%	958.0	27,231.6
109	Uruguay	3.2%	106.9	3,310.0
110	Australia	3.1%	606.3	19,866.4
111	Croatia	3.0%	124.5	4,157.1
112	Poland	3.0%	1,148.6	38,481.0
113	Norway	2.8%	110.1	3,900.2
114	Ireland	2.5%	141.5	5,579.8
115	Slovenia	2.4%	47.8	1,959.4
116	France	2.2%	1,313.4	59,617.5
117	Oman	2.0%	57.0	2,790.4
118	Spain	2.0%	782.5	39,036.7
119	Portugal	2.0%	201.9	10,205.3
120	Denmark	1.9%	94.3	5,075.2
121	Hungary	1.8%	175.5	9,989.5
122	Greece	1.6%	162.5	9,890.0
123	Slovakia	1.4%	74.4	5,432.2
124	Jordan	1.0%	80.1	8,246.7
125	Saudi Arabia	0.9%	245.4	26,608.8
126	Germany	0.8%	649.5	82,274.6
127	Canada	0.8%	247.0	32,475.2
128	Libya	0.7%	41.0	5,853.7
129	United Kingdom	0.6%	351.4	57,708.0
130	United States	0.6%	1,767.8	294,017.0
131	Sweden	0.5%	38.9	8,422.7
132	Austria	0.4%	32.8	8,192.7
133	Lebanon	0.4%	13.6	3,774.1
134	Finland	0.3%	14.6	5,064.6
135	Italy	0.3%	157.9	56,816.0
136	Trinidad And Tobago	0.3%	2.8	997.0
137	Japan	0.3%	322.5	123,693.0
138	Switzerland	0.2%	12.3	7,612.1
139	Jamaica	0.1%	2.9	2,569.2
140	Israel	0.1%	6.3	7,849.5
141	Czech Republic	0.1%	5.9	10,233.8
142	Egypt	0.0%	27.8	78,015.2
143	Taiwan	0.0%	7.4	22,371.1
144	Netherlands	0.0%	3.3	16,352.1
145	United Arab Emirates	0.0%	0.4	2,235.5
146	Belgium	0.0%	0.8	10,486.5
147	Korea, South	0.0%	3.3	46,439.5
148	Kuwait	0.0%	0.0	2,358.4