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ORIGINAL PAPER

Lighting and Homicides: Evaluating the Effect of an Electrification Policy in Rural Brazil on Violent Crime Reduction

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Abstract
Introduction This study estimates the effects of lighting on homicides in rural areas of developing countries.
Methods We use an IV strategy by exploring the LUZ PARA TODOS or Light for All (LPT) program that was adopted by the federal government to expand electrification to rural areas in Brazilian municipalities in the 2000s as an exogenous source of variations in access to electricity.
Results Our results indicate a significant decrease in homicide rates in municipalities the Northeast region, which is the poorest region of the country and most affected by the policy expansion. We estimate that helping a municipality increase from zero electricity coverage to full coverage reduces homicide rates by 92 per 100,000 inhabitants. This is equivalent to moving a municipality that is at the 99th percentile to the median (zero) of the crime distribution across municipalities. In addition, we perform placebo exercises using sub-samples of predominantly urban municipalities. The results increase our

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confidence in the IV strategy since our primary results were from areas with a larger percentage of rural population, as should be expected by the policy.
Conclusions This study contributes to the extant literature by investigating the effects of lighting on homicides in a different context, rural areas of a developing country (Brazil).

Keywords Homicide · Lighting · Hospital homicide data · Rural areas · Brazil

JEL Classification O10 · O18 · K42

Introduction

Studies regarding criminology reveal that improving street lighting is effective against certain types of crime, such as robbery, assault, burglary, and vandalism (Welsh and Farrington 2008). Most of the studies were conducted in urban areas (i.e., cities, downtown areas, residential and commercial neighborhoods, etc.) in developed countries (the United States and England) and typically used police report data (see, for example, Inskeep and Goff 1974; Painter and Farrington 1997).

In principle, lighting can have either positive or negative effects on crime. Individuals purchase more items that are targeted by criminals because access to electricity increases the demand for these items (Pease 1999). A positive gain of welfare can be lost because of criminal activities. Conversely, electrification can reduce crime because it improves the security technology that is used by the police and individuals (new weapons, cameras and surveillance technologies, alarms, etc.) and reduces individuals' exposure to violent crime (e.g., individuals stay home and use more electric devices, including watching TV, listening to the radio, etc). In addition, increased visibility makes it easier to identify a criminal offense and the offender, which increases the individual cost of crime (Becker 1968; Stigler 1970; Chalfin and McCrary 2012a).

Similarly, electrification may improve labor market outcomes, such as employment and earnings (Dinkelman 2011) and these variables can help reduce violent crimes (Gould et al. 2002; Raphael and Winter-Ebmer 2001). Prior studies regarding urban areas in developed countries suggest that crime deterrence might be more effective than other factors (see for example, Welsh and Farrington 2008).

This study contributes to the extant literature by investigating the effects of lighting on homicides in a different context, rural areas of a developing country, Brazil. We take advantage of the introduction of a comprehensive and extensive rural electrification program [*Luz para Todos*—LPT (Light for All)] that was implemented by the Brazilian Federal government in 2003. This program targeted rural areas with low electrification coverage and was designed to supply lighting to family farms, households and areas that did not have lighting, including public buildings and commercial establishments. Prior to the program's implementation, individuals lived, operated their businesses, and traveled without the use of electricity. This environment favors homicides because a lack of lighting facilitates the planning of violent crimes. Two emblematic cases occurred in northern Brazil (a rainforest area), made headline news worldwide and portray this type of violent crime: the premeditated murders of environmentalist Chico Mendes in 1988 and American environmentalist Dorothy Mae Stang in 2005.

The LPT program design helps us address potential endogeneity problems in the relationship between lighting improvements and homicides. The estimation of the effect of electrification on the homicide rate using the ordinary least squares (OLS) method is subject to classic problems regarding non-experimental data, which yields biased estimators. This occurs because the municipalities have a myriad of unobservable characteristics that might be simultaneously correlated with electrification and the homicide rate. The eligibility criteria of the LPT program are detailed below and are used to construct the instrumental variable for electricity access. The instrumental variable combined with the municipality panel data structure allow us to estimate, based on reasonable assumptions, the causal effect of electrification on the homicide rate. To our knowledge, no prior study has focused on the effects of lighting on homicides. Homicide is a crime with the highest social costs, chiefly in Latin American countries. For example, in violent societies, the reduction in life expectancy at birth due to violence can be greater than 1 year (Soares and Naritomi 2010).

In addition, this study contributes to extant literature regarding the impacts of electrification programs on individual and household outcomes. Worldwide, electrification programs have been effective in ameliorating social welfare in different areas. According to Khander et al. (2009) and Khander et al. (2012), this type of program leads to improvements in employment, income, education, and health. Several studies corroborate the benefits of electrification (Dinkelman 2011; Bensch et al. 2011; Barnes and Waddle 2004; Modi et al. 2006). Our study adds an important dimension to this literature by estimating the impact of the LPT program on violent crimes in rural areas of Brazil that gained access to electricity through the program.

Furthermore, our study has two practical advantages compared to several other studies. First, Brazil is a continental country with political and administrative divisions and includes nearly 5600 municipalities, each with an average of 20,000 inhabitants. These municipalities have constitutional autonomy and are endowed with the power to establish their own policies and make decisions regarding their budgets (expenditures and local taxes). Because of the large number of municipalities, the results of our investigation are robust. Second, homicide data are obtained from hospital reports; we avoid using police report data, which may suffer from underreporting.[1]

Notably, studying violent crimes and lighting in Brazil is interesting. First, the homicide rate is one of the largest social problems in Brazil. The relative and absolute number of murders in Brazil is alarming. In 2010, 52,260 homicides were reported, averaging more than 143 cases per day. Brazil is one of the world's 12 most populated countries and has the highest homicide rates. Brazil ranks seventh among 95 countries for the highest homicide rate per 100,000 inhabitants and is only outranked by countries that are in a state of civil war, such as the Republic of Congo, Sudan, and Afghanistan (World Bank).[2] In 2007, the Washington Post portrayed the scenario by reporting that the war between Palestine and Israel caused 729 deaths of individuals under the age of 18 between 2002 and 2006. In Rio de Janeiro, 1857 individuals under the age of 18 were murdered during the same period (Reel 2007). The perception that violence hinders welfare and affects everyday life is corroborated by the alarming figures of these offenses. Since 2008, more than 50,000 individuals have been murdered annually in Brazil (DATASUS). Furthermore, this violence is very unevenly distributed across municipalities; the median homicides per 100,000 inhabitants is equal to zero (DATASUS).[3]

Second, Brazil improved economically during the 2000s; the per capita income has increased and inequality and poverty have decreased. LPT recipients experienced welfare gains. Information provided by the Ministry of Mines and Energy of Brazil (the ministry

[1] Berg and Lauritsen (2016) mention the problems of using police report data in the US.

[2] http://databank.worldbank.org/data/reports.aspx?source=2&series=VC.IHR.PSRC.P5&country.

[3] http://datasus.saude.gov.br/.

responsible for the program) highlights the expansion of the consumption of durable goods and a return of families to rural areas in the Northeast because of the program: "The data in the survey indicate that 79.3% of respondents bought televisions and 73.3% have refrigerators now. Not to mention those who bought blenders, fans, water pumps, etc. Approximately 5% of families said they returned to the rural area after the arrival of energy. This means that 130,700 families left the large cities returning to rural areas" (Portal Brazil published: April 26, 2011).[4]

We analyze violent crimes and lighting in an environment with high but uneven levels of criminality in a period of social and economic improvement. Lighting impacts numerous channels that can affect violent crimes in different directions. The LPT program provided us an opportunity to credibly estimate the net effect of electricity on homicides. Furthermore, because we were able to obtain information regarding the places where violent deaths occurred, including rural roads/urban streets, households or hospitals, we can analyze the predominant channels that explain the results. Using 2000 and 2010 Brazilian municipality panel data and an instrumental variable (IV) approach, we determine that providing a municipality that previously had no access with full electrification in the northeast region of Brazil (this area is the poorest in the country and benefitted most from the program), the impact of electrification is 91.76 fewer homicides on rural roads per 100,000 inhabitants. This is equivalent to moving a municipality out of the 99th percentile to the median (zero) along the homicide rate distribution across municipalities. Crime on urban streets/rural roads would be virtually eliminated in Northeast region. This investigation regarding the potential mechanisms that could change Brazilians' daily life in a manner that might influence crime, demonstrates that individuals in this region demand more electric devices (e.g., refrigerators, radios, and TVs). We do not find evidence regarding labor market outcomes. These results suggest that individuals stay at home more and subsequently, are less exposed to violent crimes. Compared with the effects of dry laws on homicides (a 10% reduction) among Brazilian municipalities of the State of São Paulo (Biderman et al. 2009), an increase in electrification had a much greater effect.

To ensure that our primary results are indeed induced by the LPT program, we perform a placebo investigation on the first-stage using a different sub-sample of municipalities with a different percentage of urban population. The results demonstrate that the correlation between the criteria established for the program and electrification coverage for municipalities is more significant when the population is more rural. Therefore, these results confirm that we capture the effect of the LPT program on electricity access.

This paper is organized into six sections. The following section discusses the potential channels that associate electrification and violent crimes. "Institutional Background and Data" section presents the Brazilian institutional background and data. "Methodology" section describes the methodology and the instrumental variables with panel data. "Results" section discusses the results and "Final Remarks" section presents the final remarks.

[4] See Clarke and Weisburd (1994) regarding the benefits of controlling crime.

The Relationship Between Electrification and Violent Crimes

Why does electrification affect violent crimes? At least two theoretical developments in criminology that help us interpret the effects of electrification on crime: the rational choice theory (RCT) and the deterrence theory (DT).[5]

The RCT emphasizes that the decision to commit a crime is a rational process where the offender weighs a risky choice and will commit a crime if the expected utility from committing the crime is greater than the expected utility from not committing the crime (Becker 1968).[6,7] The probability of detection and sanctions are direct mechanisms that increase the individual's cost for committing a crime. If the individual is risk-averse, the severity of the sanction is more effective for reducing crime than the probability of detection. We expect the opposite for risk-lovers.

Conversely, the DT describes crime as a process (i.e., a sequence of actions) that depends (in this order) on prescribed punishment (i.e., legislation for crime that establishes the sanction or severity of punishment, changes in legislation, and police visibility), communication, and finally, criminal behavior. Deterrence interferes in this process through communication. The central idea is that the threat of punishment increases the risk of detection and alters the criminal behavior of individuals (Waldo and Chiricos 1972; Apel 2013).[8]

Certain critics have doubted the ability of RCT to provide a general theory for crime (De Hann and Vos 2003). Certain authors highlight that the DT can be fitted into the RCT through the probability of detection because the subjective risk perception of individuals affects this probability and subsequently, crime (Loughran et al. (2016)).[9]

In alignment with the RCT, electrification can affect the decision of an individual to commit a crime through three mechanisms. Two mechanisms are direct and one mechanism is indirect. The first direct mechanism is through the probability of detection. Electrification can increase the risk perception that an individual will be identified (through lighting) by other individuals (witnesses) or police when he or she commits a violent crime. Notably, electrification can also reduce the chances of planning a crime in rural areas because darkness adds a "surprise" element to criminals' actions. The second direct mechanism is through a reward for crime. Although its ultimate effect on crime is unclear, electrification affects the benefits of crime. Positively, lighting illuminates objects (i.e., objects of value) that individuals take with them while traveling on streets/rural roads or

[5] Another important issue is situational crime prevention (Clarke and Felson 1993; Felson 1994). Prevention techniques seek to decrease the number of suitable victims and increase the presence of control and guardians at all times. We understand that electrification per se is not a prevention technique to avoid crime. However, electrification influences the environment of crime. The line of separation between the theories is not clear cut.

[6] Studies regarding criminology attribute the foundation of RCT to Cornish and Clarke (1986). However, Loughran et al. (2016) claims that Becker (1968) was the founding author.

[7] The rational choice for individual j can be calculated by the equation: $E(Uj) = pjUj(Yj - fj) + (1 - pj)U(Yj)$; where E(Uj) represents the individual's expected utility of crime (j); p represents the probability of detection; Yj represents the benefits that the individual obtains after a successful crime; and f represents the severity of the sanction that the individual receives if he/she is apprehended.

[8] A contextual level includes the publicity of the sanction, police visibility, and sanction enforcement (prescribed punishment) and affects the risk perception of an individual and potential criminal behavior (Apel 2013).

[9] The evidence of individuals' risk perception regarding crime is negative and weak (see the overview in Apel 2013).

that they own in their homes/businesses. These objects can yield a return (reward) for criminals in the illicit markets and they commit violent crimes to obtain the object. Negatively, lighting can reduce violent crimes because individuals have more domestic goods (TVs or radios) and travel less on streets/rural roads. In regards to the rewards of crime, the indirect mechanism of labor income has to be considered. Individuals may generate labor income from legal and illegal activities. If the proportion of income from legal activity increases, individuals may desire less income from illegal activities. As a consequence, fewer violent crimes are committed. The electrification increases economic activities (Dinkelman 2011) and thus raises income from legal activities. Therefore, more income/employment (future earnings for the employee) competes with income from illegal activities (a cost of opportunity) and reduces crime (Gould et al. 2002; Raphael and Winter-Ebmer 2001).[10,11]

In alignment with the DT, we can interpret the effect of electrification as a change in communication because it amplifies information regarding punishment and the police (for example, through radio and TV, which depend on power).[12] In this case, more information regarding the sanctions increases the risk of punishment that is perceived by individuals, which can reduce homicides.

Theoretically, the net effect of electrification can either reduce or increase homicides. Therefore, this issue represents an empirical question.

The Effect of Street Lighting on Different Types of Crime

Welsh and Farrington (2008) extensively reported on the benefits of improved street lighting in regards to crime reduction. These scholars cite eight investigations on American streets and five on British streets. These studies evaluate the situation prior to and after the installation of lighting and the effects of lighting on criminal behavior. In the US, these scholars analyze the experience of the Atlanta Regional Commission (1974), whose impromptu street lighting system reduced robberies but increased burglaries in the city's downtown area. In a separate case, Milwaukee's Department of Inter-Governmental Fiscal Liaison (1973, p. 173) demonstrates that crimes against property and violence against persons are reduced in residential and commercial areas that have street lighting. In addition, Inskeep and Goff (1974) reported similar results, fewer robberies and assaults and more burglaries in the residential neighborhood of Portland. Wright et al. (1974) reported similar results for robbery, assault, and larceny and increased motor vehicle theft in residential and commercial areas in Kansas City. The Harrisburg Police Department (1976) reported similar benefits (a reduction in robberies and an increase in assault, burglaries, and motor vehicle thefts in residential neighborhoods) in Harrisburg, Pennsylvania. Sternhell (1977) demonstrates that street lighting reduces crimes such as assault, burglary, and motor vehicle theft in residential and commercial areas of New Orleans. Lewis and Sullivan (1979) reported a reduction in crime against property (burglary and theft) and a smaller reduction in crimes against persons (rape, assault, and robbery) in a residential neighborhood in Fort Worth, Texas. Finally, more violence and less crime against property were

[10] The effect on crime is not homogenous for different groups of society. Clearly, this effect is dominant for male youth.

[11] Fajnzylber et al. (2002b) estimate that a one percentage point increase in the growth rate of income per capita is associated with a 2.4% decline in homicide rates.

[12] Finan and Ferraz (2011) describe the importance of the radio as the mechanism that described the punishment of a corrupt mayor in Brazil.

reported for a residential neighborhood in Indianapolis (Quinet and Nunn 1998). In the UK, Poyner (1991) claims that improved lighting reduces the number of vehicle thefts from parking garages in Dover. Shaftoe (1994) demonstrates a reduction in car thefts and an increase in robberies in a residential neighborhood with improved street lighting (Bristol). Poyner and Webb (1992) report a similar reduction in thefts in Birmingham's downtown market. According to Painter and Farrington (1997, 2001), crime (burglary, vehicle theft, violence, vandalism, and dishonesty) decreased with the introduction of street lighting in Dudley. The authors mention that crime rates for burglary, vehicle theft, and violence decreased in Stake-on-Trent after the introduction of street lighting. Recently, Dolec and Sanders (2015) demonstrate that Daylight-Savings Time (i.e., a shift in the relationship between clock time and sunset in the US) reduces robberies by 7%.

Other Factors that Affect the Homicide Rate

Certain studies have demonstrated the effect of other public safety policies, demographics, and inequality on the homicide rate. The elevated second stage result of police manpower on violent crimes is common in US municipalities. When we consider elasticities, fire-armed police (all police are fire-armed in the US) reduce all violent crimes (Levitt 2002) by 1.39 (a 1% increase reduces crime by 139%), by 0.79 (79%, McCrary 2002, correcting a computer program error in Levitt), by 0.66 (66%, McCrary 2002, with new elections for mayor as a measure), and by approximately 30% depending on the sample (Chalfin and McCrary 2012b). In Chalfin and McCrary (2012a)'s sample, the average number of violent crimes is 972.7 per 100 K population.

For Brazilian cities in the State of São Paulo, the imposition of a dry law on commerce (a limit for bar closing hours) is associated with a significant reduction (10%) in homicide rates (Biderman et al. 2009).

In addition, population demographics affect the homicide rate. Levitt (1999) estimates that a 1% increase in the percentage of young people in the population is associated with a 0.41% increase in homicide rates in the United States.

By observing the effects of inequality, Fajnzylber et al. (2002a) estimate that a one percentage point increase in the Gini coefficient is associated with a 1.5% increase in homicide rates in several countries (cross-country study).

Institutional Background and Data

The *Luz Para Todos* (LPT) Program

The LPT program was initiated in late 2003 by the Federal Government to provide Brazilian households with public access to electricity and improve the supply of this service to communities and households that previously had no access to electricity. The program was established by the *Federal Decree* no. 4.873 of November 11, 2003 and the goal was to provide universal access by 2008.

To achieve this goal, the federal government established rules for admission into the program and the responsibilities of each government level (federal, state and local) for managing the program. The LPT program provided local electricity providers with public subsidies to give access and deliver electricity to targeted communities, farmers or households. The program was managed by the Ministry of Mining and Energy.

Municipalities that met at least one of the following criteria were considered eligible for the LPT program, priority was given to the municipality that met the most criteria:

I. Municipalities with electricity access coverage of less than 85% of the households based on the 2000 census data;
II. Municipalities with a human development index (HDI) less than their state average in 2000;
III. Communities affected by hydroelectric power plants;
IV. Communities with rural electrification projects targeted at the productive use of electric power and fostering locally integrated development;
V. Unattended public schools, health centers, and water wells;
VI. Unattended rural settlements;
VII. Unattended family farmers;
VIII. Unattended small and medium-sized farms;
IX. Communities with rural electrification projects that focused on rural communities and villages and were stalled due to a lack of funds;
X. Communities in the vicinity of nature conservation units; and
XI. Special communities, such as racial minorities, remaining *quilombo* (slave descendants) communities, extractive communities, etc.

As a result, the program expanded the transmission of electricity by more than 1.4 million kilometers of electric cables and the goal to reach 10 million households was achieved in 2009.

The financing of the LPT Program was shared by the federal and state governments and electric utilities in an agreement that was signed by the interested parties but supervised by the Brazilian National Electricity Regulatory Agency—Aneel (Brasil 2013).

Of all 5457 municipalities, 87% were eligible to LPT program under the HDI criterium, 32% were eligible under the electricity access coverage criterium, and 31% were eligible under both criteria. In practice, the IDH criterium did not discriminate the municipalities and the authorities targeted the resources according to the coverage criteria.

For regions where access to electric power supply was practically universal and the need for investment and the program was less, electric utilities were granted a smaller non-refundable loan to minimize possible tariff payments. Conversely, where the investment was greater (i.e., an increased impact on tariffs), the federal government offered elevated non-refundable loans. For example, for states in the Northeast region where tariff rates would be greater because the investment would result in a high cost for electric utilities, the federal government offered a considerable share of non-refundable loans. The federal government was responsible for 70% of the loans that were provided to the region. 66% of these loans were non-refundable. The remaining 30% were offered by state governments and electric utilities (Portal Brazil published: April 26, 2011).[13] The non-refundable loans that were granted by the federal government for different regions satisfied the electric power coverage criterion (Criterion I). Therefore, we use this criterion as a source of exogenous variation in access to electricity: LPT should provide rural electrification to municipalities with less than 85% coverage in 2000.

[13] http://www.brasil.gov.br/infraestrutura/2011/04/luz-para-todos-atende-6-milhoes-no-nordeste.

Data

In 2010, Brazil had 5565 municipalities. Our sample includes all intact municipalities in 2000 and 2010. Several new municipalities were created by dividing previous municipalities. We construct municipality panel data for 2000–2010 and exclude the municipalities that were divided between 2000 and 2010, which resulted in a total of 5457 municipalities.

All variables are obtained or constructed at the municipality level. Homicide data are obtained from the Information System on Mortality on an annual basis by DATASUS, a database organized by the Brazilian Unified Health System (SUS) of the Ministry of Health.[14] The Ministry is responsible for collecting, processing, and disclosing information regarding health inputs and outcomes from hospital and health center reports. The data are publicly available at the municipality level. Importantly, DATASUS uses a homogeneous criterion for classifying deaths across the country, which allows for comparisons across municipalities. In the specific case of homicides, the category that the system uses to measure this variable is that of the assault group within the matrix of death caused by external causes. Violent death is classified by the location of occurrence (place of death): hospital, road/street, household, and other. One advantage of this dataset is that it does not suffer from underreporting, a common problem for police report data.

The explanatory variables are obtained from the 2000 and 2010 Brazilian demographic censuses that were conducted by IBGE (Brazilian census bureau). These censuses are chosen because their samples are representative at the municipality level and the interval between the census years coincides with periods prior to and after the implementation of the LPT program.

The primary explanatory variable that was created from the demographic census is household electricity coverage at the municipality level, which refers to the percentage of households with access to electricity (% of electrification). In addition, we use a large set of demographic and economic variables as controls. We control for the age and level of education distributions.[15] The percentage of individuals in certain categories are used for age and education variables. Six categories are created for age: 8–15 years, 16–29 years, 30–39 years, 40–49 years, 50–59 years, and 60 years or older. The education variables are based on individuals who are older than 25 years and include three categories: (1) completed elementary education, (2) completed secondary education and (3) completed tertiary education. Other controls include the proportion of men in the total population (gender variable), the proportion of Caucasians (white; race/color variable), and the proportion of households in rural areas (rural variable).

We control for municipality income per capita, the unemployment rate and the Gini coefficient of household per capita income. The Gini coefficient is obtained from the United Nations Development Program (UNDP) database and the remaining variables are collected from census data. We include a state-specific time trend variable to allow for a different dependent variable's dynamics between Brazilian states. In addition, we control for the level municipalities lighting coverage in 2000 (interacting with the year dummy) to minimize the possibility of mean reversion. Finally, we control for police manpower (the number of police officers per 100,000 inhabitants) using the codes of occupation that are

[14] http://datasus.saude.gov.br/. See Cerqueira (2010).

[15] Controlling for the population and specific groups within the population is highly important in studies regarding crime. See Chalfin and McCrary (2012a) and Levitt (1998a, b).

provided in the census database.[16] Because differences exist in the classification of occupations between the 2000 and 2010 databases, occupations that are directly linked to policing are grouped with other safety-related occupations (e.g., firefighters).

To conduct our investigation on mechanisms, we constructed seven variables: earnings, employment rate (percentage of the working adult population),[17] hours worked (average hours worked by the adult working population), recent migration (percentage of individual comes from other municipalities for one period less than the last 7 years), and the proportion of households with TVs, radios and refrigerators.

Descriptive Statistics

Table 1 presents the descriptive statistics of the municipality variables for 2000 and 2010. The variables include demographic and social-economic information.

For all variables, the values reported for 2000 significantly differed from those reported for 2010 (Mann–Whitney test—nonparametric test), with the exception of two variables that are related to the labor market (occupation rate and hours worked) and the migration variable (recent migration). According to the table, the percentage of electrification coverage was on average, 86% in 2000 and 97% in 2010. In regards to age, municipalities had a young population; more than 41% of individuals were younger than 30 years old in 2000. This rate decreased to 38% in 2010. In regards to education, on average, 9% of the population aged over 25 years had completed secondary education in 2000 (this percentage increased to 16% in 2010) and only 2% had completed tertiary education (this percentage increased to 5% in 2010).

Note that the percentage of households without access to electricity decreased to 3% in 2010 from 14% in 2000. A notable result is regarding the minimum number of households that have access to electricity. In 2000, the municipality/town with the lowest coverage rate did not reach 7%; however, in 2010, the municipality/town with the lowest rate reported at least 30% access to electricity, which is far from ideal but represents a major breakthrough.

Other improvements that can be observed during this period include an increase in the real average income of municipalities, an increase of average individual´s labor earnings, an increase in the percentage of households with a TV or refrigerator; a decrease in the share of population in rural areas and radio ownership; and an decrease in the average unemployment rate.

However, in regards to criminality, the results are not encouraging. Crimes where death occurred on rural roads/urban streets increased from an average of 3.69–6.37 per 100,000 inhabitants between 2000 and 2010, which represents an increase of 72%. Crimes where violent death occurred in households increased from 2.20 to 2.91 per 100,000 inhabitants between 2000 and 2010. The number of assault-related deaths in hospitals increased from 1.28 to 1.65 per 100,000 inhabitants between 2000 and 2010. Finally, the number of homicides without a clear indication of where they occurred (other place of death) increased from 2.39 to 3.30 per 100,000 inhabitants between 2000 and 2010. There is a large dispersion in the sample regarding the place of death. For most places of death, zero to 161 homicides per 100,000 inhabitants were committed on public roads/streets.

[16] It is unclear whether police officers work for the municipal, state or federal government inside the municipality. Brazil has municipal, state, and federal police. Therefore, we consider in our measure, all individuals who are registered as police officers inside the municipality.

[17] The working adult population is defined as all individuals who are 18 years old or older and occupied as paid employees, non-paid-employees, self-employed, or receiving subsistence.

Table 1 Descriptive statistics (2000 and 2010)

Variables	2000 (5457 observations)				2010 (5457 observations)			
	Mean	S.D.	Min.	Max	Mean	S.D.	Min.	Max
% of electrification	0.86***	0.16	0.07	1	0.97	0.05	0.30	1
% of local population aged 8–15 years	0.17***	0.02	0.08	0.30	0.15	0.02	0.04	0.26
% of local population aged 16–29 years	0.24***	0.02	0.14	0.33	0.23	0.02	0.11	0.44
% of local population aged 30–39 years	0.13***	0.02	0.06	0.21	0.14	0.01	0.08	0.27
% of local population aged 40–49 years	0.10***	0.02	0.04	0.21	0.12	0.02	0.05	0.20
% of local population aged 50–59 years	0.07***	0.01	0.02	0.17	0.09	0.02	0.03	0.21
% of local population aged 60 years or older	0.09***	0.02	0.01	0.22	0.12	0.03	0.02	0.26
% of Caucasians in the total population	0.53***	0.25	0.008	1	0.47	0.23	0.01	0.99
% of men in the total population	0.50***	0.01	0.43	0.61	0.50	0.01	0.45	0.81
% of population in rural areas	0.40***	0.22	0	1	0.34	0.21	0	0.95
Population	30,815.56***	187,414.2	795	1.04e+07	34,609.99	204,997	805	1.13e+07
% of population completed elementary education	0.08***	0.03	0	0.26	0.11	0.03	0.02	0.33
% of population completed secondary education	0.09***	0.04	0.003	0.35	0.16	0.06	0.02	0.47
% of population completed tertiary education	0.02***	0.02	0	0.25	0.05	0.03	0.003	0.33
Unemployment rate	11.10***	6.21	0	59.17	6.79	3.82	0	41.93
Income per capita	338.13***	193.43	62.65	1759.76	492.49	244.09	96.25	2043.74
Gini coefficient	0.54***	0.06	0.30	0.87	0.49	0.06	0.28	0.80
Police manpower (100,000 inhabitants)	70.30***	55.43	0	545.34	110.09	98.49	0	1169.59
Log-earnings	5.86***	0.58	4.13	7.62	6.07	0.50	4.56	7.62
Occupation rate	0.58	0.09	0.19	0.93	0.58	0.09	0.21	0.95
Hours worked	40.73	4.49	23.08	58.67	40.76	4.56	19.81	57.35
Recent migration	0.15	0.08	0.01	0.80	0.15	0.08	0.006	0.89
% of households with TV	0.73***	0.18	0.03	0.99	0.89	0.08	0.16	1
% of households with a radio	0.80***	0.12	0.22	1	0.77	0.13	0.13	0.99

Table 1 continued

Variables	2000 (5457 observations)				2010 (5457 observations)			
	Mean	S.D.	Min.	Max	Mean	S.D.	Min.	Max
% of households with a refrigerator	0.67***	0.23	0.002	1	0.87	0.11	0.16	1
Homicides (100,000 inhabitants)—Place of death								
Rural Road/Urban Street	3.69***	8.26	0	100.94	6.37	11.76	0	161.10
Household	2.20***	5.97	0	85.76	2.91	6.36	0	86.05
Hospital	1.28***	4.18	0	75.33	1.65	4.61	0	81.99
Other	2.39***	6.59	0	104.16	3.30	6.93	0	76.89

Mann–Whitney test (z-statistic) *** $p < 0.01$; ** $p < 0.05$; * $p < 0$

Table 2 provides the descriptive statistics by region for the pooled years of 2000 and 2010: north, northeast, southeast, south, and midwest. The southeast region of Brazil is the most populated and wealthiest. The north and northeast regions are the poorest.

Electrification differed across regions and rural road/urban street homicide rates were higher in regions where electrification was slightly lower. The data are as asymmetric as those obtained from national surveys. We constructed two figures (see "Appendix"—Figs. 3, 4) to illustrate the distribution of electricity across Brazilian municipalities in 2000 and 2010. Clearly, the northern and northeastern regions (top of the figures) have the least amount of coverage (2000).

Methodology

Instrumental variables are used to estimate the effect of electrification on crime rates, particularly the homicide rate per 100,000 inhabitants. As briefly discussed in the introduction, the simple estimation of equations that link homicide rates to electrification using OLS likely yields biased results. This bias is likely to occur because of the time-varying unobservable characteristics of municipalities that are concomitantly correlated with electrification and crime rates. For example, cities/towns whose mayors can manage funds and apply public policies more efficiently could have lower homicide rates and greater access to electricity. In this case, the estimation of the parameters that measure the effect of local electrification on local homicide rates provides information on not only the causal relationship between access to electricity and homicides but also the quality of the mayor's management, which may change over time. Additionally, inverse causality is possible. For example, the places where crime rates increased because of, e.g., greater local control by mobs and gangs, are the locations where access to public services showed the smallest increase.

The instrumental variables method is applied using two-stage estimations. The first stage includes estimating an equation that determines access to electricity based on instrumental variable and other exogenous variables. We obtained our variable from the first priority criteria of the LPT program. A good instrumental variable is one that is correlated with the endogenous variable, households' access to electricity but is not directly correlated with unobservable factors that affect the main dependent variable, the homicide rate. The first hypothesis can be statistically tested by conducting a validity test of the instruments that are calculated in the first stage regression. The second hypothesis is an identification assumption; however, its reasonableness can be analyzed from a theoretical/economic perspective.

In this study, the second hypothesis of the instrumental variables method assumes that the LPT program is not related to the unobservable factors that determine homicide rates at the local level. It is reasonable to assume this hypothesis because the criteria of the LPT program are not influenced by municipalities; the program was created by the federal government through a discontinuity rule on the coverage variable that makes municipalities eligible. Therefore, the instrumental variable is used as an indicator variable for the eligibility criteria for the LPT program: household electricity coverage in 2000. The municipalities that met the criteria in 2000 are believed to have an increased likelihood for the expansion of electrification in the last decade. Because the additional controls that include the coverage of 2000 interacted with a time dummy, our estimation is a parametric linear fuzzy regression discontinuity design.

Table 2 Descriptive statistics by region (2000 and 2010)

Variables	North (798 observations)				Northeast (3574 observations)				Southeast (3332 observations)			
	Mean	S.D.	Min.	Max	Mean	S.D.	Min.	Max	Mean	S.D.	Min.	Max
% of electrification	0.75	0.18	0.16	0.99	0.86	0.16	0.07	1	0.96	0.06	0.33	1
% of local population aged 8–15 years	0.19	0.02	0.10	0.30	0.18	0.02	0.10	0.26	0.15	0.02	0.04	0.25
% of local population aged 16–29 years	0.25	0.02	0.17	0.33	0.25	0.01	0.18	0.33	0.23	0.02	0.15	0.44
% of local population aged 30–39 years	0.12	0.02	0.06	0.21	0.12	0.01	0.06	0.21	0.14	0.01	0.09	0.27
% of local population aged 40–49 years	0.09	0.01	0.04	0.14	0.09	0.01	0.05	0.16	0.12	0.01	0.06	0.20
% of local population aged 50–59 years	0.06	0.01	0.02	0.11	0.07	0.01	0.03	0.13	0.09	0.01	0.03	0.16
% of local population aged 60 years or older	0.06	0.02	0.01	0.13	0.10	0.02	0.02	0.19	0.11	0.03	0.03	0.25
% of Caucasians in the total population	0.52	0.09	0.01	0.86	0.30	0.11	0.008	0.86	0.58	0.19	0.07	0.98
% of men in the total population	0.52	0.01	0.47	0.61	0.50	0.01	0.45	0.56	0.50	0.01	0.43	0.81
% of population in rural areas	0.44	0.19	0	0.95	0.46	0.19	0	0.98	0.27	0.19	0	0.86
Population	32,630.01	111,734.7	958	1802,014	28,164.38	103,928.9	1253	2675,656	45,744.97	320,415.8	795	1.13e+07
% of population completed elementary education	0.09	0.03	0.01	0.22	0.07	0.03	0	0.33	0.11	0.03	0.008	0.26
% of population completed secondary education	0.12	0.06	0.008	0.38	0.10	0.05	0.003	0.47	0.14	0.06	0.006	0.40

Table 2 continued

Variables	North (798 observations)				Northeast (3574 observations)				Southeast (3332 observations)			
	Mean	S.D.	Min.	Max	Mean	S.D.	Min.	Max	Mean	S.D.	Min.	Max
% of population completed tertiary education	0.02	0.02	0	0.20	0.02	0.01	0	0.19	0.05	0.03	0	0.33
Unemployment rate	10.45	6.31	0.48	59.17	10.15	5.81	0	45.28	9.41	5.30	0	35.57
Income per capita	277.15	128.25	62.65	1087.35	223.31	101.03	63.5	1144.26	514.65	216.29	85.69	2043.74
Gini coefficient	0.58	0.06	0.42	0.81	0.54	0.05	0.35	0.82	0.49	0.06	0.32	0.78
Police manpower (100,000 inhabitants)	118.14	118.90	0	1169.59	88.14	78.91	0	716.96	88.85	81.37	0	846.92
Log-earnings	5.52	0.44	4.13	6.99	5.32	0.40	4.15	7.04	6.15	0.43	4.45	7.62
Occupation rate	0.54	0.08	0.20	0.78	0.52	0.07	0.19	0.86	0.58	0.06	0.23	0.82
Hours worked	39.43	4.74	19.81	57.83	37.32	4.06	23.52	53.90	42.81	3.21	23.08	58.42
Recent migration	0.18	0.11	0.06	0.75	0.11	0.05	0.01	0.52	0.15	0.07	0.02	0.10
% of households with TV	0.62	0.20	0.06	0.97	0.75	0.18	0.03	0.98	0.88	0.11	0.16	1
% of households with a radio	0.55	0.11	0.13	0.83	0.72	0.11	0.18	0.95	0.83	0.07	0.13	0.98
% of households with a refrigerator	0.58	0.21	0.10	0.96	0.62	0.21	0.02	0.99	0.86	0.15	0.12	1
Rural Road/Urban Street	5.35	10.38	0	76.67	6.79	12.14	0	161.10	3.80	8.61	0	110.43
Household	2.91	7.06	0	85.99	2.38	5.28	0	58.02	2.04	5.46	0	86.05
Hospital	1.78	5.07	0	81.99	1.01	3.85	0	66.07	1.87	4.93	0	75.33
Other	3.86	7.68	0	60.55	2.70	5.87	0	76.89	2.23	5.72	0	98.23

Variables	South (2318 observations)				Midwest (892 observations)			
	Mean	S.D.	Min.	Max	Mean	S.D.	Min.	Max
% of electrification	0.97	0.04	0.50	1	0.93	0.09	0.36	1
% of local population aged 8–15 years	0.14	0.02	0.07	0.23	0.15	0.02	0.08	0.24
% of local population aged 16–29 years	0.22	0.02	0.11	0.30	0.24	0.02	0.17	0.33
% of local population aged 30–39 years	0.14	0.02	0.08	0.21	0.15	0.01	0.09	0.20
% of local population aged 40–49 years	0.13	0.01	0.07	0.21	0.12	0.01	0.06	0.18

Table 2 continued

Variables	South (2318 observations)				Midwest (892 observations)			
	Mean	S.D.	Min.	Max	Mean	S.D.	Min.	Max
% of local population aged 50–59 years	0.10	0.02	0.04	0.21	0.08	0.02	0.03	0.15
% of local population aged 60 years or older	0.12	0.03	0.03	0.26	0.09	0.03	0.01	0.19
% of Caucasians in the total population	0.81	0.12	0.22	1	0.45	0.12	0.11	0.93
% of men in the total population	0.50	0.01	0.46	0.63	0.51	0.01	0.47	0.57
% of population in rural areas	0.40	0.23	0	1	0.29	0.17	0	0.80
Population	22,589.06	76,717.31	1113	1751,907	28,638.19	133,604.6	895	2570,160
% of population completed elementary education	0.12	0.03	0.02	0.33	0.11	0.03	0.03	0.22
% of population completed secondary education	0.13	0.05	0.004	0.36	0.14	0.05	0.02	0.35
% of population completed tertiary education	0.04	0.03	0	0.31	0.04	0.03	0	0.23
Unemployment rate	5.91	4.56	0	40.59	8.91	4.46	1.23	27.01
Income per capita	583.29	217.69	156.51	1798.12	500.64	174.95	116.72	1715.11
Gini coefficient	0.49	0.07	0.28	0.08	0.52	0.07	0.36	0.87
Police manpower (100,000 inhabitants)	73.82	60.57	0	632.11	120.95	93.73	0	912.40
Log-earnings	6.30	0.37	5.05	7.49	6.15	0.34	4.75	7.44
Occupation rate	0.67	0.09	0.34	0.95	0.60	0.06	0.25	0.79
Hours worked	42.36	3.45	21.47	58.67	43.76	3.87	29.43	57.35
Recent migration	0.15	0.06	0.02	0.61	0.23	0.11	0.02	0.89
% of households with TV	0.89	0.09	0.25	0.99	0.81	0.13	0.24	0.98
% of households with a radio	0.91	0.05	0.36	1	0.72	0.10	0.27	0.91
% of households with a refrigerator	0.92	0.08	0.36	1	0.82	0.14	0.25	0.99
Rural Road/Urban Street	3.61	8.61	0	132.21	5.94	10.25	0	100.94
Household	2.72	7.08	0	80.97	4.37	8.06	0	68.39
Hospital	1.17	3.56	0	51.58	2.23	5.39	0	54.64
Other	2.52	6.91	0	81.63	5.64	10.71	0	104.16

Our first-stage is given by the following equation:

$$E_{mt} = \alpha_0 + \alpha_1\left(year_t * EletrificationCriteria_m^{2000}\right) + \alpha_2\left(year_t * Coverage_m^{2000}\right) + \sum_{j=1}^{k} \rho_j X_{jmt} + \varphi_m + \mu_{st} + year_t + \varepsilon_{mt} \quad (1)$$

E_{mt} represents the percentage of households with access to electricity in municipality m in period t. The $EletrificationCriteria_m^{2000}$ indicator variable assumes a value equal to one if access to electricity in municipality m in 2000 is less than 85% and zero otherwise. The variable $year_t * EletrificationCriteria_m^{2000}$ is the instrumental variable that is obtained from the interaction between the indicator variable $\mathrm{year_t}$, in which observations for year 2010 are assigned value 1 (and zero otherwise) and the dummies for compliance with the quantitative criteria of the LPT program. The k variables represented by $\mathrm{X_{jmt}}$ indicate the controls that are used and represent the percentage of individuals per age group, average educational attainment, race/color dummies, percentage of men the total population, percentage in rural/urban location of household, income per capita, unemployment rate, municipality size (population), income distribution index (Gini coefficient), and police manpower (number of police officials per 100,000 inhabitants). In addition, we control for electrification coverage in 2000 interacted with the year dummy ($year_t * Coverage_m^{2000}$). The term μ_{st} represents the state-specific time trend. Finally, φ_m represents the fixed effect of the municipality, $year_t$ represents the year 2010 indicator variable and ε_{mt} is the idiosyncratic error term.

The second stage equation is as follows:

$$Y_{mt} = \beta_0 + \beta_1 \hat{E}_{mt} + \beta_2\left(year_t * Coverage_m^{2000}\right) + \sum_{j=1}^{k} \omega_j X_{jmt} + year_t + \varphi_m + \mu_{st} + \epsilon_{mt}, \quad (2)$$

where Y_{mt} represents the homicide rate per 100,000 inhabitants in municipality m in period t, and $\hat{E}_{mt}$ represents the predicted value of the percentage of households with access to electricity in municipality m from the first-stage estimation. The covariates are the same as in the first stage. The coefficient of interest is β_1. Similar strategies have been used in electrification studies in Bangladesh and South Africa (Khander et al. 2012; Dinkelman 2011).

The specification includes controls for municipalities' demographic and social characteristics that are likely to be associated with the crime rate: the percentage of young individuals and adults, percentages of ethnic/color groups, gender, and percentage of households in rural areas. In addition to controlling for these variables, we control for education variables, assuming that a higher level of education leads to a reduction in crime rates. Economic variables include the unemployment rate and income per capita for the municipality because favorable working conditions and income tend to reduce crime rates. This tendency is noted by Raphael and Winter-Ebmer (2001), who report a positive effect of unemployment on crime rates and conclude that policies that seek to improve the level of employment of individuals who have greater difficulties entering the labor market may be an effective measure against crime and increase the opportunity cost for unlawful actions. An equity factor and a policing variable are also controlled for, in alignment with prior studies (Di Tella and Schargrodsky 2004; Draca et al. 2011).

Note that we explore the variation that results from changes in electricity coverage between 2000 and 2010 across eligible and non-eligible municipalities over and above the linear trend on coverage. We assume that the difference in the change in the electricity coverage over and above the linear trend among eligible (compared to non-eligible) municipalities is exogenous because it is induced by the LPT program. We produce two sets of figures to illustrate this effect (see the "Appendix"). The first set includes six subfigures (Fig. 1) of changes in violent crimes between 2000 and 2010 along the distribution of electricity coverage in 2000. Five of these subfigures represent Brazil's regions (North, Northeast, Southeast, South, and Midwest) and one represents Brazil as a whole. The second set (Fig. 2) includes four subfigures of violent crimes by places of death (rural road/urban street, household, hospital, and other places) in the Northeast region, which is the region where we obtain our primary results.

Each figure depicts non-parametric regression discontinuity estimations of second order polynomials (following Calonico et al. (2014)).[18] The running variable is the electricity coverage in 2000 and the cut-off value is 85% access to electricity. The (eligible) group of municipalities with less initial access to electricity in 2000 is on left side of the cut-off point and the (non-eligible) group of municipalities with greater initial access to electricity in 2000 is on right side of the cut-off. Figure 1 demonstrates that eligible municipalities (below 85% access to electricity) in 2000 immediately below the cut-off value had a smaller increase in violent crimes between 2000 and 2010 in Brazil compared to those that are just above the cut-off value. This effect is mostly driven by the impacts on the North, Northeast, and Midwest regions.

Finally, Fig. 2 indicates a smaller increase in violent crimes in all places of death in the Northeast region. Although small, there are clear discontinuities between eligible and non-eligible municipalities along the coverage criteria.

Results

Table 3 provides the results of the estimation of Eq. (1), the first stage of the instrumental variables method. The coefficients estimated for the instruments confirm the hypothesis regarding the use of the LPT program rule as instrumental variables for household electrification. The criterion of electrification coverage in 2000 is significantly different from zero and has the expected sign. The results demonstrate that the municipalities that met the electrification criterion for program eligibility increased their electricity coverage by 2.8 percentage points more than those that did not satisfy this criterion. The F-statistic of the excluded instruments indicates that they are strongly correlated with electricity coverage.

Table 4 provides both the pooling OLS and the second stage estimates for the entire country. We identify where each homicide occurred but not where lighting was available in the municipality (private or public area). To examine possible explanations, we investigate the electrification coverage effect on homicides (per 100,000 inhabitants) by the location of the violent death: all places, rural roads/urban streets, households, hospitals and other places (places that were not properly identified).

Table 4 provides two types of results. First, the pooling OLS results with only observable controls (see table note) indicates a positive correlation between access to electrification and violent homicides for all places, rural roads/urban streets, hospitals, and

[18] All figures are constructed using Calonico et al.'s (2014) methodology.

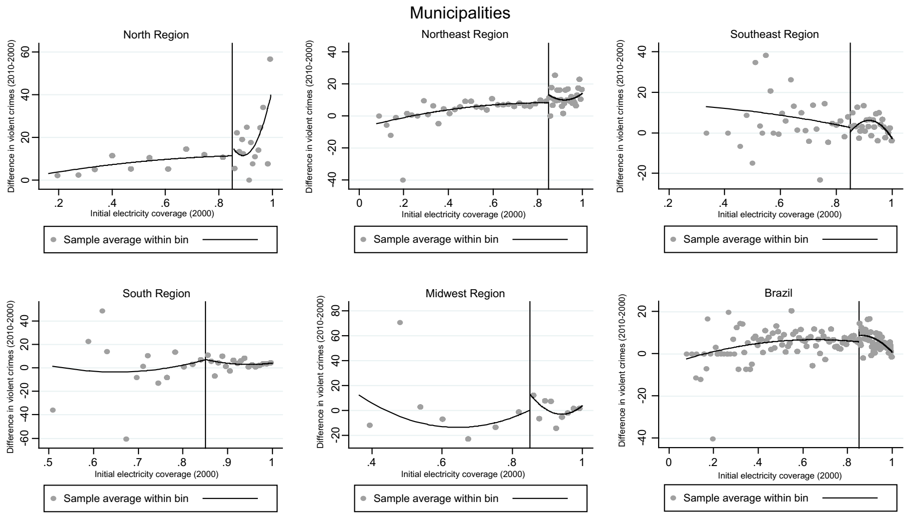

Fig. 1 Evolution of violent crimes and the initial access to electricity. *Note* Regression function fit (Calonico et al. 2014); 2nd order polinomial

other places, with an exception of homicides in households.[19] Second, the IV results with all controls indicate a negative effect of electrification coverage on homicides that occur on rural roads/urban streets, households and hospitals. Additionally, we note a positive effect on homicides at other locations. Although non-significant, the comparison of OLS and IV results indicate the direction and size of bias of a naïve approach. Places with greater coverage of electricity are richer, more populated and more urban and likely to have greater incidences of crimes. Controlling for observable and non-observable characteristics that are associated with electrification and crime and using a valid IV for electrification, the causal effect of electrification on crime can be estimated. The stronger negative impact on crime reduction on public streets may be attributed to the use of electrification; lighting is regarded as the first improvement prompted by access to electric power.

Results by Brazilian Macro-regions

The first-stage results for each region are presented in Table 6 in the "Appendix". The F-statistic of the excluded instruments indicates that the primary result is observed only for the North, Northeast, and South regions. The correlation between the Electrification criterion and electricity coverage does not exist for the Southeast and Midwest regions. These results are consistent with the fact that the LPT was more concentrated in regions with lower initial coverages. An eligible municipality in the Northeast increased its coverage by 3.2 p.p.

Table 5 provides the results for the second-stage regression for each of the five Brazilian regions. The LPT program was primarily concentrated in municipalities in the North and

[19] Table 8 in the "Appendix" provides the IV results with only observable controls (non-significant) and the reduced form between our instrument variable (electrification criterion^{2000} * Year dummy (2010)) and homicides (positive and significant at 10% level).

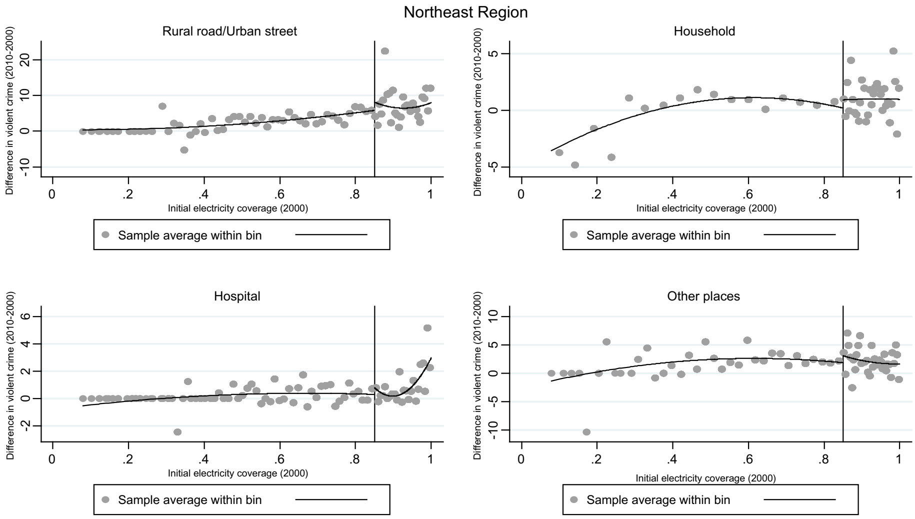

Fig. 2 Evolution of violent crimes by place of death and the initial access to electricity. *Note* Regression function fit (Calonico et al. 2014); 2nd order polinomial

the Northeast regions, where electricity coverage was the lowest in 2000 and increased the most between 2000 and 2010.

The second stage results indicate a negative and significant impact of electricity coverage on homicides in the Northeast, the poorest region of Brazil that also had the lowest coverage of electrification when compared with other regions. We do not have sufficient evidences to explain the significant difference in the second stage results among North and Northeast regions. We can speculate that the individuals in northern region are more scattered and isolated (there is a jungle) and so the dissuasive effect of lighting is weaker.

Lighting is important to reduce the number of violent deaths on public streets (urban streets or rural roads) and in hospitals (i.e., the hospital variable reflects general violence given that this is the place of death). Helping a municipality that previously had no access to achieve full access to electricity is associated with a reduction in 91.76 violent deaths on public streets per 100,000 inhabitants. The crime dispersion across municipalities ranged from 0 to 161.10 homicides per 100,000 inhabitants and the median was zero. This result is significant. The effect corresponds to moving a municipality from the 99th percentile (51.81 homicides) to the median (zero). Our intuition is that lighting protects victims.

Similarly, municipalities that previously had no access to electricity and increased to full access were associated with a reduction of 17.61 violent deaths in hospitals per 100,000 inhabitants, which represents a large impact. The crime dispersion ranged from 0 to 66.07 homicides per 100,000 inhabitants and the median was zero. The effect corresponds to moving a municipality from the 95th percentile (6.43—99th percentile is 19.11) to the median (zero).

We think the difference between our result and the literature is only the context. Our results are mostly for rural areas in poor regions among those municipalities that were induced to have lighting by the LPT program. The results from literature are in the urban context.

Table 3 First-stage results

Variables	Dependent variable: % of electrification
Electrification criterion^{2000}*Year dummy (2010)	0.028***
	(0.003)
Year dummy (2010)	0.640***
	(0.018)
Municipal fixed effect?	*Yes*
State-specific tendency?	*Yes*
Year dummy*Coverage 2000?	*Yes*
Observations	10,914
F (1;5456)	73.41***

*** $p < 0.01$; ** $p < 0.05$; Standard deviations appear in parentheses and are clustered by municipality (see Bertrand et al. 2004); Control variables: percentage of different age groups (aged 8–15 years, aged 16–29 years, aged 30–39 years, aged 40–49 years, aged 50–59 years, and aged 60 years or older), proportion of Caucasians in the total population, percentage of men in the total population, percentage of population in rural areas, percentage of population in different educational groups (completed elementary education, completed secondary education, and completed tertiary education), local population, local unemployment rate, local income per capita, local Gini coefficient, and police manpower

Welsh and Farrington (2008) provide an extensive report regarding the benefits of improved street lighting for reducing crime. These scholars cite eight investigations on American streets and five on British streets. These investigations evaluate the situation prior to and after the installation of lighting and the effects of lighting on criminality. The elasticity for different crimes in the US and UK is relatively high, averaging between 20% and 50%. In the case of Atlanta, the effects of street lighting on crimes are stronger: a 418.2% reduction in assaults and a 319.2% decrease in other crimes.

Possible Channels

One possible explanation for our results is that electrification may have altered police behavior. Although our results control for the presence of police, we do not analyze police data to determine if (rural) police effort explains the outcome. If the police are arresting more criminals in this region, the results may be affected by police effort (deterrence and/or incapacitation; see Levitt 1998a). Unfortunately, we do not include data regarding police effort and cannot explore this issue.

However, we investigate a set of variables to explore two other mechanisms that could alter individuals' daily behavior in a manner that might influence crime (see the results in Table 9 in the "Appendix"). First, individuals who have access to electricity in their homes use products (e.g., refrigerators, radios, and TVs) that may be more visible to criminals (Pease 1999) or they may stay at home longer and subsequently avoid violent crimes. Applying the same methodological procedures that were used for our primary results (IV), we note that individuals possess more TVs, radios, and refrigerators in eligible municipalities between 2010 and 2000 in the Northeast region. Therefore, because of an increase in the use of home electronics, individuals may spend more time at home and avoid the risk of violent crimes. For example, a 1 percentage point in electrification (0.01) increases 1.18 percentage points of households with TVs, 0.03 percentage points of households with radios, and 1.16 percentage points of households with refrigerators.

Table 4 Lighting and homicides by place of death—Brazil

Variable	Dependent variable								
	Homicides per 100,000 inhabitants								
	All Places	Rural Road/Urban Street		Household		Hospital		Other	
	OLS	OLS	IV	OLS	IV	OLS	IV	OLS	IV
% of electrification	16,158***	9416***	− 41.747	− 0.385	− 20.569	2.137***	− 12.905	3892***	0.677
	(1595)	(0.915)	(26.700)	(0.286)	(18.730)	(0.703)	(8.754)	(0.621)	(18.730)
Municipal fixed effect?	*No*	*No*	*Yes*	*No*	*Yes*	*No*	*Yes*	*No*	*Yes*
Year dummy? (2010)	*No*	*No*	*Yes*	*No*	*Yes*	*No*	*Yes*	*No*	*Yes*
State-specific tendency?	*No*	*No*	*Yes*	*No*	*Yes*	*No*	*Yes*	*No*	*Yes*
Year dummy*coverage 2000?	*No*	*No*	*Yes*	*No*	*Yes*	*No*	*Yes*	*No*	*Yes*
R^2	0.132	0.100	0.131	0.198	0.010	0.013	0.040	0.034	0.063
Observations	10,194	10,194	10,194	10,194	10,194	10,194	10,194	10,194	10,194

*** $p < 0.01$ ** $p < 0.05$; Standard deviations appear in parentheses and are clustered by municipality (see Bertrand et al. 2004); Control variables: percentage of different age groups (aged 8–15 years, aged 16–29 years, aged 30–39 years, aged 40–49 years, aged 50–59 years, and aged 60 years or older), proportion of Caucasians in the total population, percentage of men in the total population, percentage of population in rural areas, percentage of population in different educational groups (completed elementary education, completed secondary education, and completed tertiary education), local population, local unemployment rate, local income per capita, local Gini coefficient, and police manpower

Table 5 Lighting and homicides by place of death—different Brazilian Regions

Place of death	Dependent variable				
	Homicides per 100,000 inhabitants on				
	IV North	IV Northeast	IV Southeast	IV South	IV Midwest
Rural Road /Urban Street	− 42.912	− 91.762**	− 817.417	73.249	42.200
	(65.759)	(36.270)	(1909.005)	(128.529)	(1063.693)
R^2	0.257	0.188	− 3.739	0.066	− 1.015
Observations	798	3574	3332	2318	892
Household	30.845	− 12.584	− 563.704	− 215.644	− 9.165
	(34.784)	(19.536)	(1408.881)	(113.355)	(1058.079)
R^2	0.145	0.038	− 3.564	− 0.226	0.053
Observations	798	3574	3332	2318	892
Hospital	− 16.976	− 17.618**	− 163.162	4.809	− 331.429
	(40.462)	(8.594)	(457.183)	(26.539)	(1548.793)
R^2	0.086	0.097	− 0.471	0.047	− 8.897
Observations	798	3574	3332	2318	892
Other	61.983	− 10.618	− 357.557	31.617	1023.119
	(38.827)	(17.656)	(959.442)	(103.662)	(4457.063)
R^2	0.115	0.119	− 1.490	0.022	− 16.548
Observations	798	3574	3332	2318	892
Municipal fixed effect?	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
State-specific tendency?	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Year dummy? (2010)	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Year dummy*Coverage 2000?	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*

*** $p < 0.01$; ** $p < 0.05$; Standard deviations appear in parentheses and are clustered by municipality (see Bertrand et al. 2004); Control variables: percentage of different age groups (aged 8–15 years, aged 16–29 years, aged 30–39 years, aged 40–49 years, aged 50–59 years, and aged 60 years or older), proportion of Caucasians in the total population, percentage of men in the total population, percentage of population in rural areas, percentage of population in different educational groups (completed elementary education, completed secondary education, completed tertiary education), local population, local unemployment rate, local income per capita, local Gini coefficient, and police manpower

Second, access to electricity may affect labor market outcomes such as employment or earnings (e.g., Dinkelman (2011)). It is well documented that labor market conditions can affect crime incidence. We perform the same analysis for the following labor market outcomes: employment rate, hours worked, and log-earnings. We use the IV approach that we used for the primary results using the same controls with the exception of local unemployment rate and local income per capita. The results demonstrate that electrification does not affect employment, hours worked or earnings in the Northeast region. Therefore, it appears that the labor market channels can be ruled out as a potential explanation.

Placebos

We conducted the first-stage regression for a different sub-sample of municipalities with a different percentage of the population living in rural areas as placebo exercises. We separated the municipalities in quartiles of the percentage of rural population in 2000 (the first quartile is 25% or less of an urban population, the second quartile is less than the median rural population in Brazil, the third quartile is higher than the median, and the last quartile is 25%—and more of an urban population). The results demonstrate that the correlation between the criterion of electrification and coverage is a rural phenomenon (see Table 7 in the "Appendix"). The first-stage result is not significantly different from zero for municipalities with a low incidence of rural population and is positive and significant for municipalities with a greater incidence of rural population. Therefore, these results suggest that we capture the effect of the LPT program on electricity coverage.

In summary, the results suggest that the LPT program has a positive impact on the supply of electricity to municipalities with higher levels of rural population and reduces violent deaths (homicides), particularly those that occur on rural roads/urban streets. The effect occurs in the poorest region (Northeast) that has the least amount of electricity coverage in the country.

Spillover Effect of Violent Crimes in the Northeast Region[20]

In principle, spillover effects may explain our results. Criminals migrated from an eligible municipality to a non-eligible municipality to commit crimes. Although there is the possibility of individual adhesion of each municipality in the federal program, because of the significant subsidy, we observe (compare the Figs. 3 and 4 in the "Appendix") that access to the program was practically universal between 2000 and 2010. Although several issues affect the rational decisions of individuals who consider committing a crime (see the recent developments reported by Loughran et al. 2016), the area of coverage in the Northeast does not suggest that a municipal reduction in violent crime caused by lighting is related to the migration of this type of crime to municipalities with less coverage. We observe that the access to electrification does not provoke significant changes on migration (see Table 9 in the "Appendix").

Final Remarks

Numerous studies have demonstrated that household electrification is beneficial to the communities that receive this service and results in positive externalities. Improvements related to municipalities' access to electricity include better school enrollment rates; improved production techniques that subsequently increase productivity; and health benefits that include a reduction in hunger, the use of cleaner energy, a reduction in pulmonary disorders and better information regarding disease prevention. This study sought to assess the benefits of electrification in regards to a reduction in violent deaths (homicides per 100,000 inhabitants), which is a topic that has not been well addressed in prior studies.

We contribute to the extant literature by estimating the relationship between electrification and homicide (violent crime) rates, yielding robust results (a large number of municipalities) for a developing country, and avoiding underreporting (hospital data). Because we use an IV strategy by exploring the LPT program eligibility criteria, we can interpret the results as the estimated impact of the program on municipalities that

[20] Spillover effects are used on hot-spots and studies regarding problem-oriented policing (see Chalfin and McCrary 2012a). In addition, see Braga and Weisburd (2010) regarding crime hot-spots.

experienced an increase in electricity coverage because of their program eligibility. Therefore, the results represent local average treatment effects of lighting on homicides.

The results regarding homicides per place of death indicate that the expansion of electrification reduces murder rates on public roads or streets. Prior studies support this result. The categorization per region revealed that our results are circumscribed to the Northeast region, which is the poorest and has the least access to electricity.

Our results regarding violent deaths (homicides per 100,000 inhabitants) are sizable and robust. A municipality in the northeastern region that increased from zero access to electricity to full electrification would move from a percentile slightly above the 99th percentile to the median (no homicides per 100,000 inhabitants, which represents a reduction of 91.76 per 100, 000 inhabitants for public areas).

This result is consistent with the assumption that lighting allows for the easier identification of suspects, which increases the opportunity cost and deters crime. In addition, this result aligns with Clarke and Mayhew (1980), who demonstrate that crimes may be affected by the physical features of the environment where they occur and well-lit areas may help prevent crimes. Moreover, there are additional non-conflicting alternative explanations. By investigating the mechanisms that could change individuals' daily lives in a manner that might influence crime, we observe that individuals possess more home electric devices (e.g., refrigerators, radios, and TVs) in the Northeast region. Therefore, individuals may stay at home more and avoid violent crimes. Our results reinforce the idea that homicides have more to do with situational and environmental factors than any underlying causes of crime.

Verifying this significant impact offers public policymakers the opportunity to reduce crime rates. This benefit can be applied concurrently with other crime-fighting measures.

Appendix

See Tables 6, 7, 8 and 9 and Figs. 3 and 4.

Table 6 First-stage results—different regions

Variables	Dependent variable				
	Proportion of households with access to electricity in the municipality				
	North	Northeast	Southeast	South	Midwest
Electrification criterion*Year dummy (2010)	0.040***	0.032***	0.003	0.022***	0.002
	(0.010)	(0.004)	(0.007)	(0.006)	(0.009)
Year dummy (2010)	0.422***	0.733***	0.754***	0.026***	0.612***
	(0.041)	(0.021)	(0.037)	(0.006)	(0.049)
Municipal fixed effect?	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
State-specific tendency?	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Year dummy*coverage 2000?	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
R^2	0.946	0.960	0.914	0.898	0.923
Observations	798	3574	3332	2318	892

Table 6 continued

Variables	Dependent variable				
	Proportion of households with access to electricity in the municipality				
	North	Northeast	Southeast	South	Midwest
F-statistic	(1398) =18.07***	(1,1786) =59.30***	(1,1665) =0.17	(1,1158) =11.64***	(1445) =0.06

*** $p < 0.01$; ** $p < 0.05$; Standard deviations appear in parentheses and are clustered by municipality (see Bertrand et al. 2004); Control variables: percentage of different age groups (aged 8–15 years, aged 16–29 years, aged 30–39 years, aged 40–49 years, aged 50–59 years, and aged 60 years or older), proportion of Caucasians in the total population, percentage of men in the total population, percentage of population in rural areas, percentage of population in different educational groups (completed elementary education, completed secondary education, and completed tertiary education), local population, local unemployment rate, local income per capita, local Gini coefficient, and police manpower

Table 7 First-stage results Placebo—different sub-sample for the percentage of population in rural areas

	Dependent variable			
	Proportion of households with access to electricity in the municipality			
	< First quartile (with more urban population)	< Median	≥ Median	> Last Quartile (with more rural population)
Electrification criterion*Year dummy (2010)	0.009	0.012***	0.037***	0.045***
	(0.009)	(0.003)	(0.004)	(0.006)
Year dummy (2010)	0.453***	0.620***	0.607***	0.678***
	(0.045)	(0.021)	(0.022)	(0.024)
Municipal fixed effect?	*Yes*	*Yes*	*Yes*	*Yes*
State-specific tendency?	*Yes*	*Yes*	*Yes*	*Yes*
Year dummy*Coverage 2000?	*Yes*	*Yes*	*Yes*	*Yes*
R^2	0.837	0.913	0.951	0.952
Observations	2728	5456	5458	2728
F-statistic	(1,1363) = 1.21	(1,2727) = 11.59***	(1,2728) = 95.02***	(1,1363) = 66.25***

*** $p < 0.01$ ** $p < 0.05$; Standard deviations appear in parentheses and are clustered by municipality (see Bertrand et al. 2004); Control variables: percentage of different age groups (aged 8–15 years, aged 16–29 years, aged 30–39 years, aged 40–49 years, aged 50–59 years, and aged 60 years or older), proportion of Caucasians in the total population, percentage of men in the total population, percentage of population in rural areas, percentage of population in different educational groups (completed elementary education, completed secondary education, and completed tertiary education), local population, local unemployment rate, local income per capita, local Gini coefficient, and police manpower

Table 8 Lighting and homicides by Place of Death—Brazil

Variable	Dependent variable	
	Homicides per 100,000 inhabitants	
	All Places	
	IV	Reduced Form
% of electrification	0.438	–
	(3.815)	–
R^2	0.074	–
	First-Stage	–
Electrification criterion^{2000}*Year dummy (2010)	0.197***	0.965*
	(0.003)	(0.559)
F(1;5456)	3878,00***	–
Municipal fixed effect?	*No*	*No*
Year dummy? (2010)	*No*	*No*
State-specific tendency?	*No*	*No*
Year dummy*coverage 2000?	*No*	*No*
R^2	0.811	0.126
Observations	10,194	10,194

*** $p < 0.01$ ** $p < 0.05$; Standard deviations appear in parentheses and are clustered by municipality (see Bertrand et al. 2004); Control variables: percentage of different age groups (aged 8–15 years, aged 16–29 years, aged 30–39 years, aged 40–49 years, aged 50–59 years, and aged 60 years or older), proportion of Caucasians in the total population, percentage of men in the total population, percentage of population in rural areas, percentage of population in different educational groups (completed elementary education, completed secondary education, and completed tertiary education), local population, local unemployment rate, local income per capita, local Gini coefficient, and police manpower

Table 9 Other mechanisms—Northeast

Variable	Dependent variable						
	Households with TV[a] IV Second Stage	Households with a radio[a] IV	Households with a refrigerator[a] IV	Occupation rate[b] IV	Hours worked[b] IV	Log-earnings[b] IV	Recent migration[a] IV
% of electrification	1.18***	0.032***	1.16***	− 0.06	− 0.376	0.463	− 0.17
	(0.14)	(0.004)	(0.14)	(0.21)	(11,224)	(0.386)	(0.12)
Municipal fixed effect?	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Year dummy (2010)?	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
State-specific tendency?	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Year dummy*coverage 2000?	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
R^2	0.954	0.297	0.971	0.976	0.985	0.975	0.987
Observations	3574	3574	3574	3574	3574	3574	3574

*** $p < 0.01$ ** $p < 0.05$; Standard deviations appear in parentheses and are clustered by municipality (see Bertrand et al. 2004); Control variables: (a) percentage of different age groups (aged 8–15 years, aged 16–29 years, aged 30–39 years, aged 40–49 years, aged 50–59 years, and aged 60 years or older), proportion of Caucasians in the total population, percentage of men in the total population, percentage of population in rural areas, percentage of population in different educational groups (completed elementary education, completed secondary education, and completed tertiary education), local population, local unemployment rate, local income per capita, local Gini coefficient, and police manpower; (b) the same controls of (a) excluding the local unemployment rate and local income per capita

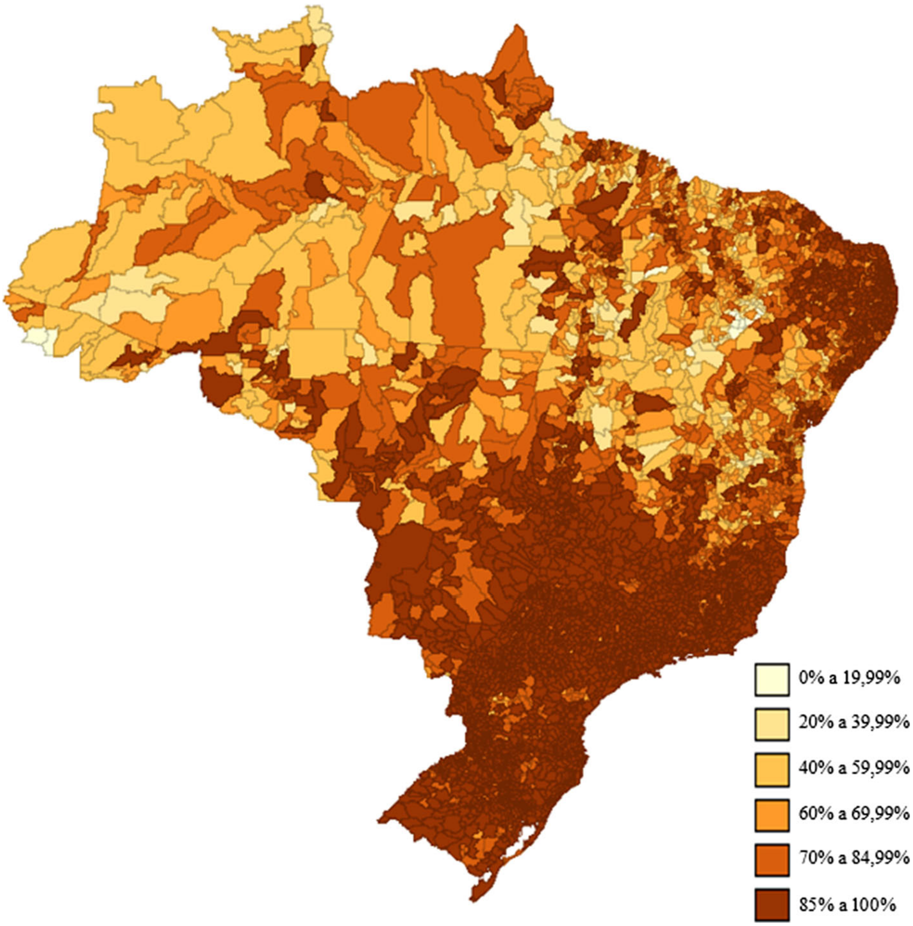

Fig. 3 Proportion of households with access to electricity in 2000 (5507 municipalities)

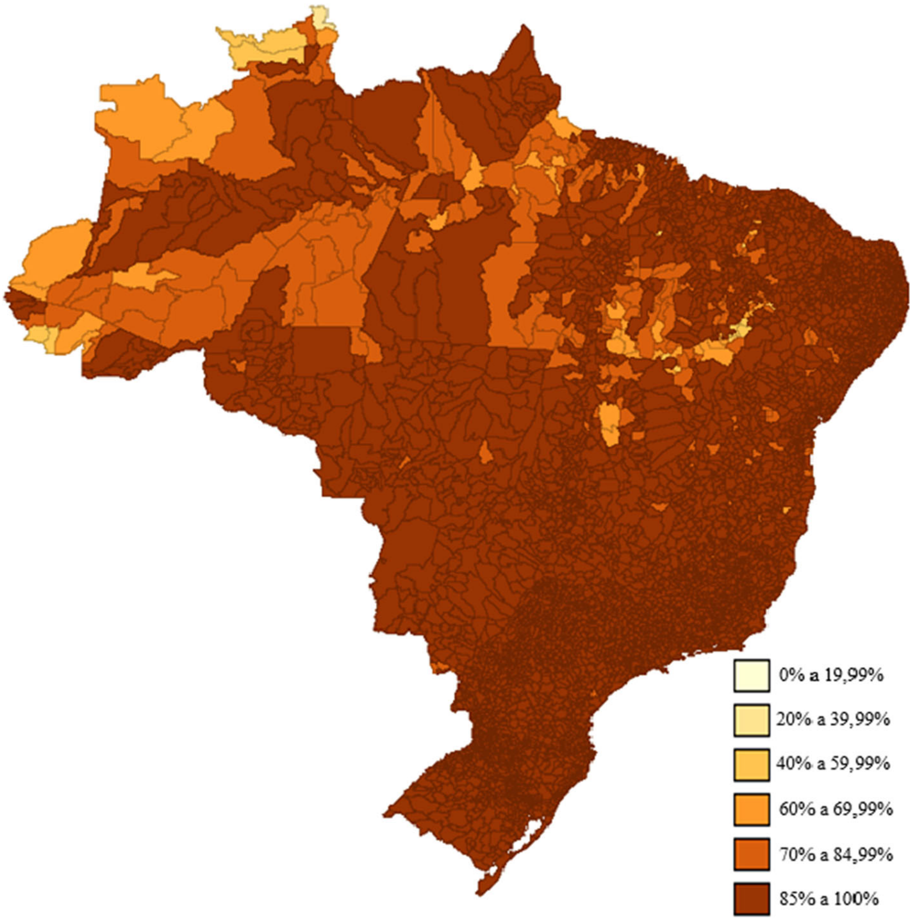

Fig. 4 Proportion of households with access to electricity in 2010 (5507 municipalities)

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