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The local socio-economic impacts of large hydropower plant development in a developing country

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ABSTRACT

Despite extensive discussion in the literature about the socio-economic impacts of hydropower development on surrounding communities, there is (1) a lack of quantitative studies that look at impacts over extended periods of time and (2) a lack of studies including multiple projects in the context of a developing country. Here, we use econometric methods to evaluate the relationship between county-level socio-economic indicators and hydropower development for 56 Brazilian hydropower plants built between 1991 and 2010. We find that counties that built hydropower plants had greater GDP and tax revenues during their first few years of development than a control group that consisted of counties with hydropower projects planned but not yet built. However, those positive economic effects were short lived (<15 years). We also find that social indicators (e.g. average income, life expectancy, educational level, access to piped water and public electricity, teenage pregnancy levels, and HIV cases) in counties that built hydropower did not statistically differ from those in the control counties. The results suggest that, for Brazil, justifications for hydropower projects based on local long-term economic and social development should be questioned, and that more effective mechanisms for turning local short-term economic growth into long-term development are needed.

1. Introduction

The idea that large dams, by increasing irrigation and electricity production, can increase development and reduce poverty has led developing countries and international agencies, such as the World Bank, to undertake major investments in dam construction (Duflo and Pande, 2007). Hydropower is regarded as an important electricity generation option because it provides electricity efficiently, reliably (Egré and Milewski, 2002), and at a relatively low cost (Intergovernmental Panel on Climate Change (IPCC), 2011). Additionally, hydropower has the potential to provide important ancillary services to the electric system (Hug-Glanzmann, 2011), as well as non-energy services like flood control and irrigation (Von Sperling, 2012). The construction of a hydropower plant, like other energy projects, requires substantial investment and employs a significant number of people, with the potential to increase economic activity and tax revenues in surrounding regions (Feyrer et al., 2015; Newell and Raimi, 2015; Kline and Moretti, 2014) — an argument often used to muster support for these projects.

The recent development of large hydropower plants in countries like China and Brazil has also stimulated debate about the economic (Ansar et al., 2014), social (Jackson and Sleigh, 2000; Tilt et al., 2009), and environmental (Fearnside, 2006, 2015) effects of these projects. Economic impacts could be positive (e.g. higher income, better infrastructure) if the electricity revenues are shared with the local communities (Koch, 2002), or negative, if local agents absorb the costs associated with hydropower development (e.g., road repairs due to heavy truck traffic (Newell and Raimi, 2015), loss of productive agricultural and forest land (Duflo and Pande, 2007), and reduction of fishing resources (da Silva Soito and Freitas, 2011)). For example, in the case of irrigation dams in India, a study by Duflo and Pande found that agricultural production increased and rural poverty declined in districts located downstream from the dam, but rural poverty increased in the district where the dam was built. Furthermore, with the implementation of high tension transmission lines, electricity can be transmitted thousands of kilometers away from the generating plant, meaning local communities may not directly benefit from increased electricity supply (Severnini, 2014).

In terms of social impacts, the influx of workers seeking jobs stresses local infrastructure (e.g., hospitals and housing) (da Silva Soito and Freitas, 2011), and may lead to socially undesirable outcomes, such as increases in sexually transmitted diseases (Lerer and Scudder, 1999), crime (Rosenberg et al., 1997), and drug use (Von Sperling, 2012). The resettlement of those who live in the reservoir areas, and the encroachment by outsiders (Rosenberg et al., 1995), may also lead to

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deterioration of social cohesion (Von Sperling, 2012; Jackson and Sleigh, 2000; Lerer and Scudder, 1999; Brown et al., 2009). In terms of environmental impacts, hydropower projects change the biogeochemical cycles of ecosystems by interrupting the river course, changing the nutrient balance, and shifting the flow of oxygen, heat, and sediment flow (Friedl and Wuest, 2002; Manyari and de Carvalho Jr, 2007). Further, the fragmentation of the river ecosystem affects migration of aquatic species, and the flooding of large areas harms local biodiversity (Von Sperling, 2012; Rosenberg et al., 1995).

Here we focus on the short- and long-term local socio-economic impacts from hydropower development, a critical question for several stakeholders, including governments, that must make decisions about urban planning, electricity subsidies, and tax structure, as well as local communities that require realistic assessments of the likely benefits and costs, of hydropower development. Despite the important socio-economic impacts of hydropower development, there are few studies examining local impacts in developing countries (Jackson and Sleigh, 2000; Fearnside, 2001; Sovacool and Bulan, 2011). In addition, available studies are limited to qualitative evaluations of just one or two projects. As a result, there are unanswered questions about impacts associated with hydropower development. For instance, what happens to county-level economic activity during dam construction and operation? Do socio-economic conditions after the construction of a hydropower plant improve, and if so, for how long?

Using publicly available data we investigate the relationship between hydropower development and the socio-economic conditions in Brazilian counties from 1991 to 2010. We find that counties that built hydropower plants had a gross domestic product (GDP) that was, on average, 10% (95% CI: 4% to 16%) greater per year during peak construction than counties with hydropower projects planned but not yet built (the control group). After completion of plant construction, that difference diminished, and 14 years after the beginning of construction, the average difference was just 3% (95% CI: −1% to 7%). We find a similar temporary increase for public revenues (e.g., local tax, and state and federal transfers). Lastly, although we cannot rule out sizeable negative effects, we find little evidence that social indicators (e.g. average income, life expectancy, educational level, access to piped water, access to public electricity, teenage pregnancy levels, and HIV cases) in counties that built hydropower plants differ from those that had plans to build plants that never materialized.

Our results indicate that in Brazil, the justification for hydropower projects based on long-term economic and social development for local communities lacks empirical support. Nevertheless, given that electricity transmission may foster economic growth in distant places, our findings suggest that transfers to counties where dams are constructed may make all counties better off after hydropower development. Thus, more effective compensation mechanisms should be designed to assure that local communities are properly compensated for hydropower development for the long-term use of their local natural resources.

2. Brazilian context

Brazil offers a unique setting to explore the socio-economic impacts of hydropower development because the country has 203 large (>30 MW of installed capacity) hydropower plants in operation, and 10 under construction (ANEEL — Agencia Nacional de Energia Eletrica (Brazilian Electricity Agency), 2016). In Brazil, hydropower proponents have emphasized the local positive socio-economic impacts on communities around hydropower reservoirs. This view is regularly expressed in environmental impact assessments (EIAs), which evaluate the social and environmental viability of large infrastructure projects such as hydropower plants, and are required by Brazilian environmental law. A review of recent Amazon hydroelectric EIAs indicates that hydro dams are expected to improve economic activity and social welfare in surrounding regions. The long-term drivers of economic growth usually mentioned in those reports are 1) the water resources financial compensation (WRFC), and 2) an increase in tax revenues (Eletrobras, 2009; EPE, 2010a, 2011, 2010b).

The WRFC is a legal mechanism that requires hydro dam owners to pay a fee for the water used to produce electricity. The fee is 6.75% of the monthly total energy produced by power plants multiplied by an energy tariff. The energy tariff is defined annually by the Brazilian electricity agency – ANEEL – that is also responsible for collecting and distributing the WRFC fees. According to the law, 45% of the total WRFC resources are allocated to counties affected by the reservoirs, 45% to the states where the counties are located, and 10% to the federal government. In 2014, 183 hydropower reservoirs paid WRFC fees to ANEEL totaling 1.7 billion reais (~470 million USD given March 2016 foreign exchange rates) (ANEEL, 2015a). The idea behind the WRFC is to compensate places affected by hydropower reservoirs to mitigate social and environmental impacts, hoping to improve local welfare. The resources are allocated to counties proportionally according to the share of the reservoir area in each county.

The construction of large dams imposes a series of challenges for policy makers and planners, including the influx of thousands of temporary construction workers. Table 1 describes the migration problem using EIA data from recent Amazon projects. Note that the number of jobs generated by each project can be significant when compared to the population size of the affected regions. Hydropower sites are often in rural areas with low population density. In the extreme cases of the Sao Manoel and Teles Pires projects, the number of jobs is greater than the population size.

3. Conceptual framework

Fig. 1 illustrates our conceptual framework, showing the potential economic pathways of counties affected by hydropower development. Before construction, we assume no effect on local economic activity. We do not consider the possible, but unlikely, case that businesses, people, and investment flow into the community surrounding a hydropower plant well in advance of the construction commencement.

During the construction period, economic activity may grow and reach a peak before the beginning of plant operation. This growth might occur for two reasons. The first is the significant investment (millions to billions of dollars) to build the dam and other structures, such as the spillway and the powerhouse, resulting in increased local tax revenue. The second is the direct employment of thousands of workers for a significant period of time (3 to 8 years), who spend their money on local goods and services, and the creation of indirect jobs for local businesses that provide those goods and services.

After construction ends and operation begins, multiple pathways are possible. The number of jobs directly involved in the operation of the hydropower plant may vary from a few dozen to a few thousand workers, depending on the size of the plant. The owners of the hydropower plant may pay local taxes, potentially supporting further development. Further, if new industries are attracted to the counties affected by the hydropower facility, other jobs will be created in the region.

Pathway 1 shows a positive outcome of the post-construction operational phase, where hydropower plants draw more workers, people, and investment to the region, leading to sustained growth. This new economic activity might result from having economic agents in the same physical space, creating opportunities for knowledge transfer, pooling of specialized skills, and taking advantage of the local natural resources (Severnini, 2014).

Pathway 2 is a slightly less positive view about the post-construction phase. Growth in affected counties is still higher than counties where dams are planned but not built, but there is a reduction in the local economic activity during the operation period compared to the construction peak. In this scenario most of the construction workers leave the region looking for new opportunities, but the revenues from the hydropower plant and other activities attracted by the dam support

Table 1
Expected job creation in recent hydropower plants studies.

Hydropower project	Affected counties	Population	Estimated job creation (from EIAs)
Jirau e Santo Antonio	Porto Velho	442,701	40,000 (direct, construction peak), Furnas et al. (2008)
Belo Monte	Altamira, Anapu, Brasil Novo, Senador José Porfírio, Vitória do Xingu	166,450	18,000 (direct) and 2000 (indirect), Eletrobras (2009)
Sao Luis do Tapajos	Trairão, Ibaituba	115,211	13,000 (direct) and 12,500 (indirect), Eletrobras (2014)
Sao Manoel e Teles Pires	Paranaíta, Jacareacanga	25,088	14,000 (direct) and 36,000 (indirect), EPE (2010a); EPE (2011)
Sinop	Sinop, Sorriso, Ipiranga do Norte, Cláudia e Itauba	211,260	3000 (direct), EPE (2010b)

higher economic development. In both Pathways 1 and 2 the hydropower facility improves local economic activity, and at least part of the electricity generated by the dam is consumed locally.

Pathways 3 and 4 represent cases where local economic growth occurs primarily during the construction period. In Pathway 3, economic activity carries some momentum from the dam construction, but workers and new businesses slowly leave the region because of the lack of new opportunities or investments. In Pathway 4 there is no momentum, and construction employees leave immediately after the end of the construction. In this scenario, local economic activity quickly returns to the same level relative to the control group. In Pathways 3 and 4, hydropower plants do not provide long-term benefits to the local economy, and the electricity generated by the dam is consumed far from the production site.

We use this conceptual framework to examine the socio-economic pathways of Brazilian counties during hydropower development. Specifically, Brazilian environmental impact assessments expect Pathways 1 or 2, with long-term positive socio-economic impacts that extend beyond dam construction, while Pathways 3 or 4 represent alternative possible scenarios, where investments and jobs quickly enter and leave the region during construction.

4. Data and methods

4.1. Data

To evaluate the effect of hydropower development on local economies, we gathered gross domestic product (GDP) and public revenue data for 5565 Brazilian counties. GDP data came from the *Instituto Brasileiro de Geografia e Estatística* (I.B. de Geografia e Estatística IBGE, 2016) and are available from 1999 to 2010. While the National Treasure Secretary is the primary source of public budget data in Brazil (S. do Tesouro Nacional, 2010), we collected this information from the *Instituto de Pesquisa Economica Aplicada* (IPEA) (I. de Pesquisa Economica Aplicada IPEA, 2015) because this institution was the only source providing annual data from 1991 to 1998. Furthermore, IPEA performed a reanalysis of the National Treasure Secretary dataset adjusting for currency changes, and also standardized according to counties created from 1991 to 2010. Thus, our data include tax revenue information for each county between 1991 and 2010.

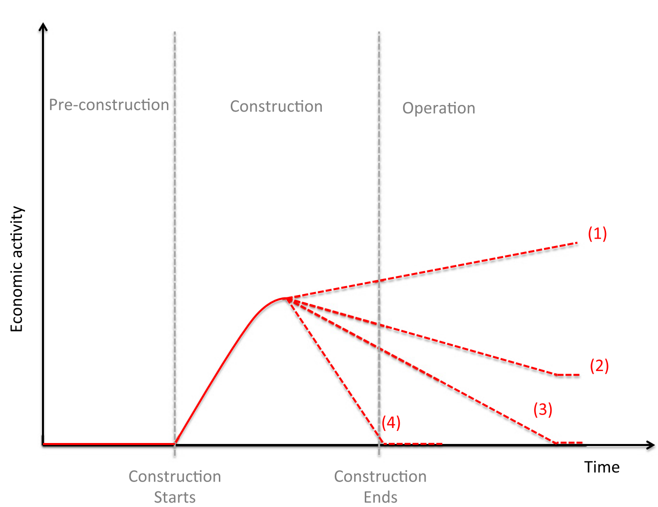

Fig. 1. Conceptual framework describing possible local economic activity pathways during construction and operation of a large hydropower plant. Red lines represent possible pathways of local economic activity relative to counties where dams are planned but not built.

We also collected data from the electric sector agency, ANEEL, to identify the counties that have hydropower plants within their borders (ANEEL, 2015a). Fig. 2 shows the spatial distribution of hydropower plants built in Brazil between 1991 and 2010. Despite the financial incentives available to support hydropower development in Brazil, many areas with hydropower potential do not succeed in developing their hydropower resources. We employ those counties where there were plans to build plants that never materialized as our control group.

To evaluate the effect of hydropower development on local social conditions, we use human development indicators, for each county, that came from the Human Development Brazilian Atlas (U.N.D.P. UNEP et al., 2015). The Atlas database relies on micro-data from the 1991, 2000, and 2010s Brazilian censuses. We use 3 indices available in this database (*Income*, *Longevity*, and *Education*) to characterize the key socio-economic dimensions of each county. Eqs. (1), (2) and (3) define the three dependent variables for each county i:

$$Longevity_i = \frac{Lifeexpectancy_i - \min\{Lifeexpectancy\}}{\max\{Lifeexpectancy\} - \min\{Lifeexpectancy\}} \quad (1)$$

where life expectancy at birth is measured in years. The minimum and maximum life expectancy values adopted by IPEA are 25 and 85 years old, respectively.

$$Education_i = \frac{\left(A_i + 2 * \frac{B_i + C_i + D_i + E_i}{4}\right)}{3} \quad (2)$$

where A is the percentage of adults (18 and older) with primary education; B is the percentage of children between 5 and 6 years old in school; C is the percentage of children between 11 and 13 years in the final years of primary school; D is the percentage of children between 15 and 17 years old who completed primary school; and E is the percentage of young adults between 18 and 20 years old with a high school degree.

$$Income_i = \frac{\ln(Income\ per\ capita_i) - \ln(\min\ reference\ value)}{\ln(\max\ reference\ value) - \ln(\min\ reference\ value)} \quad (3)$$

where *Income per capita* is the county's average income, and the maximum and minimum reference values adopted by IPEA are 4033 and 8 reais (real values based on August 2010), respectively.

In addition, we examined other indicators that may be affected by hydropower development: the percentage of public access to electricity and piped water, population density, HIV cases, and teenage pregnancy. Data on access to energy and electricity (% of serviced households) and teenage pregnancy rates (% of women pregnant between 12 and 17 years old) also come from the Atlas (U.N.D.P. UNEP et al., 2015). HIV cases came from the health system database: DATASUS (Ministério da Saúde, 2016).

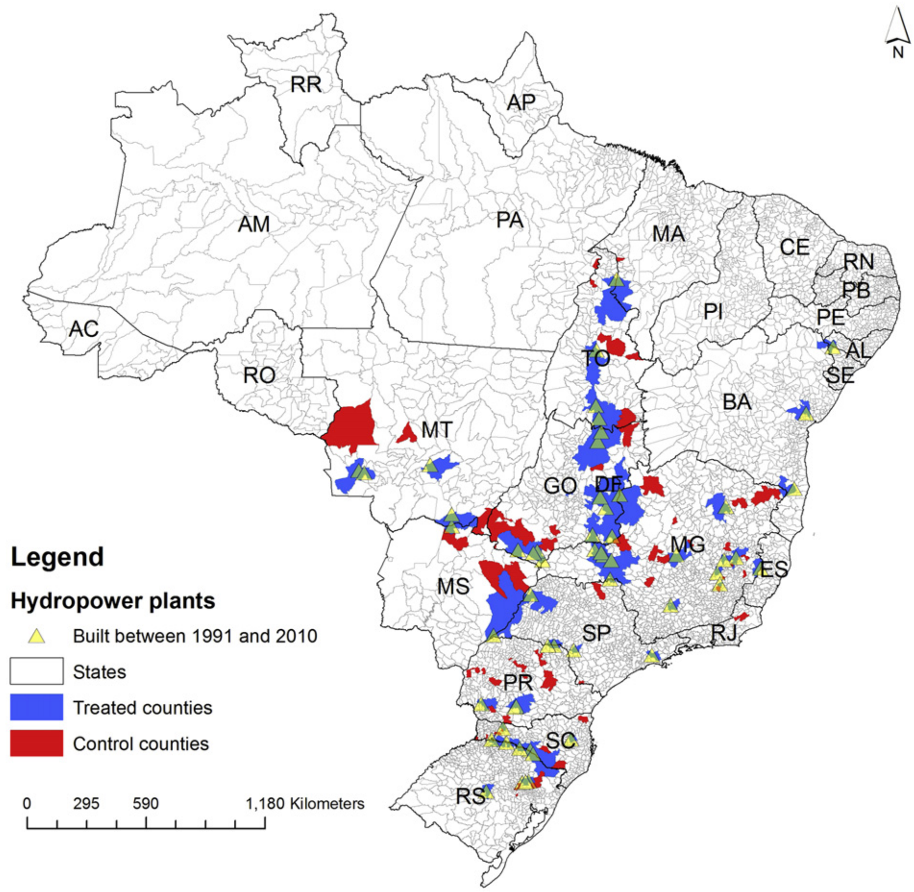

Fig. 2. Spatial distribution of hydropower plants in Brazil and affected counties. Treated group represents counties with hydropower plants built between 1991 and 2000. Control group represents counties with undeveloped hydropower projects by 2010 within a distance of 200 km from the treated counties.

4.2. Methods

4.2.1. Event-study framework

We use an event-study approach (Severnini, 2014; Jacobson et al., 1993; McCrary, 2007; Kline, 2012) to examine the relationship between hydropower plant construction and local economic activity. Hydropower plant construction happens at different times in different counties. The event study framework exploits two of the major strengths of our database – the long period of time and the presence of many counties – in order to obtain a detailed picture of the economic activity patterns across both time and space (Jacobson et al., 1993).

In the event-study approach, counties treated earlier (those who got hydropower earlier in our period of analysis) are compared with counties treated later and with control counties. They are compared before hydropower plants are constructed and after these projects begin operation. By comparing all treated and control counties with themselves across time, we eliminate any time-invariant differences between groups. By comparing counties treated earlier versus later, we eliminate any common factors related to the timing of the event (beginning of construction), assuming the underlying forces leading to hydropower development at any point in time are similar for all treated locations. Finally, by comparing all treated and control counties with each other, we eliminate any effects that occur over time, assuming these effects apply to all treated and control counties equally (U.N.D.P. UNEP et al., 2015). Eq. (4) describes the mathematical formulation of the econometric model 1:

$$\text{Model 1}: \quad EconomicIndicator_{it} = \sum_{y} \beta_y D_{it}^{y} + \phi_t + \alpha_i + \gamma_k X_{k,it} + \epsilon_{it} \quad (4)$$

where $EconomicIndicator_{it}$ is the log of GDP (total, industry, services, or agriculture) or public revenue (total public revenue, ISS, ICMS, and FPM) indicators in county i in year t. We control for county fixed effects, α_i, and year fixed effects, ϕ_t. We also include a list of control variables defined by the matrix X_k, which attempt to account for heterogeneous characteristics across Brazilian counties. γ_k is a vector of the control variables coefficients. First, we include the state GDP to account for the spatial correlation between counties from the same state. Second, we include yearly average temperature and precipitation to control for exogenous time-varying attributes of each county. Third, we include the amount of Itaipu royalties per capita received by each county. Hydropower plants located in the Parana River basin can receive additional funds from Itaipu (the second largest power plants in the world) because they regulate the downstream water flows to Itaipu allowing the optimization of the energy production. Thus, this variable is required because the royalties are correlated with the dependent variable and event-time dummies. e_{it} is the error term assumed to be mean-independent of the regressors conditional on county and time fixed effects.

Our main analysis is on the D_{it}^{y}'s, that are "event-time" dummies that equal one when hydropower construction is y periods away in a given treated county. Formally, we have:

$$D_{it}^{y} = I[t - e_c = y] \quad (5)$$

where $I[.]$ is an indicator function for the expression in brackets being true, and e_c is the year that construction of a hydropower plant starts in county i (Severnini, 2014; Kline, 2012). Therefore, the β_y coefficients in Eq. (4) represent the time track of the economic indicator relative to the construction starting date, controlling for observed and unobserved (time-invariant) heterogeneity. As a result, if hydro dams are randomly assigned to the counties, the restriction $\beta_y = 0$ should hold for all $y < 0$. In other words, the hydropower plant construction should not be, on average, preceded by trends in the counties' economic indicators. We normalize $\beta_{-1} = 0$ because not all the β_y can be identified due to collinearity between the D's and county fixed effects (Kline, 2012). Finally, we impose end point restrictions:

$$\beta_y = \begin{cases} \bar{\beta}, & \text{if } y \geq 15 \\ \underline{\beta}, & \text{if } y \leq -5 \end{cases} \tag{6}$$

which indicate that any dynamics wear off after 15 years (Kline, 2012). This constraint helps to reduce part of the collinearity between the year and event-time dummies. Because the sample is unbalanced in event time, these endpoint coefficients give unequal weight to counties affected by hydropower early or late in the sample (Kline, 2012). For this reason, we focus the analysis on the event-time coefficients falling between three years before construction and 14 years after construction, where the year 0 is the first year of construction.

The event-study approach relies on the assumption that the characteristics of the counties with plans to develop hydropower projects that do not materialize are similar to those counties that actually had hydropower constructed earlier or later in our period of analysis (random process assumption), conditional on observables. If this assumption is met, we can remove biases associated with siting decisions (e.g., natural advantages (Severnini, 2014; Rosenthal and Strange, 2004), profit maximization (Greenstone et al., 2010)) and the timing of construction (e.g., construction prices and technology advancements). Fortunately, we were able to test and confirm this assumption within this framework by looking at the behavior of the outcome variable prior to hydropower development. If the assumption is reasonable then there should be no observable differences in the event-study coefficients before construction begins, as is the case in our analysis.

4.2.2. Control group

Control group counties had formal plans to build hydropower plants, but as of the time of data collection, had not begun construction. To identify those counties, we cross-referenced the counties' map with a database provided by ANEEL that contains the precise location of hydropower plant sites studied and approved by the agency (ANEEL, 2015b). This database has information about the projects' characteristics and their development stages (master plan, viability, basic design, under construction, operation). Table 2 summarizes the development stage for the hydropower plant site used to identify the control counties.

According to the Brazilian regulatory process, the first phase for hydropower development consists of the elaboration of a watershed master plan (inventário hidrelétrico). In the master plan phase, the entire river course is divided into several hydropower plants that are designed to produce electricity using technical, economic, environmental, and social criteria. The hydropower plant design should minimize construction costs and environmental/social impacts, and at the same time, maximize electricity generation. ANEEL evaluates and approves the watershed master plans developed by private companies or the government. Thirty-nine hydropower plant sites in the control group were still in the master plan phase in 2014. Those sites are still in the first phase of development for several reasons including: the master plan is under a new review; low financial returns; or evident environmental or social restrictions (e.g., a city, a national park, or indigenous reserve).

After the site identification in the master plan phase, potential investors develop a viability study and submit a report to ANEEL. Seventeen control counties are at some stage (under development, under analysis, or approved by ANEEL) of the viability phase. After the approval of the viability study, the government organizes the public auction of the hydropower plant to investors and the winner receives the grant to develop the facility. Six hydropower plants applied to define the control counties were granted to investors in 2014.

After winning the auction, investors develop and submit the basic design, which is a more detailed planning/engineering study of the hydropower plant than the viability phase to be submitted to ANEEL. Ten hydropower plants used to define the control counties are in some part of the basic design phase (under development, under analysis, or approved by ANEEL). Also, some sites can be canceled (e.g., the project is rejected by federal/state environmental protect agencies) or suspended for regulatory issues (e.g., the investor did not follow regulatory rules) through the hydropower development process. The complete regulatory process (from the master plan to the construction authorization) in the agency is long and takes from five to dozens of years.

Table 3 summarizes the characteristics of the treatment and control groups. We focus on two outcomes related to economic activity: GDP and public revenue. We also break down tax revenue information by its main subaccounts: local services tax (ISS), state transfers (ICMS), and federal government transfers (FPM). The SI includes details about the public revenue breakdown. Table 3 shows that treated and control groups are similar for all indicators (e.g. industry GDP) except Agricultural GDP. This difference may be due to the higher average area of control counties, or chance. To account for those differences, we include control covariates in the regression models (see Eq. (4)).

4.2.3. County creation issue

Between 1991 and 2010, more than a thousand new counties were created in Brazil. This may create a problem for our analysis as the observation unit (county) changed over time. To overcome this issue,

Table 2
Description of the development stages of each potential hydropower plant site used to define the control counties.

Site situation	Number of sites
Site available for interested investors (master plan)	39
Viability design under development	9
Viability design accepted by ANEEL	5
Viability design approved by ANEEL	3
Granted to investors	6
Basic design under development	2
Basic design accepted for analysis by ANEEL	8
Basic design approved by ANEEL	1
Suspended	9
Canceled	1
Not informed	1

Table 3
County sample statistics (T = treatment and C = controls).

	Group	Mean	Standard deviation	n	*t*-test
Gross domestic product (1999)					
Log Total GDP (reais)	T	11.1	1.4	214	−0.66
	C	11.2	1.3	84	
Log Industry GDP (reais)	T	8.9	2.1	214	0.19
	C	8.8	2.0	84	
Log Services GDP (reais)	T	10.4	1.4	214	−0.74
	C	10.5	1.3	84	
Log Agriculture GDP (reais)	T	9.2	1.1	214	−3.33
	C	9.7	1.1	84	
Public revenues (1991)					
Log Public revenue (reais)	T	5.0	1.9	214	−0.85
	C	5.2	1.8	84	
Log Services tax – ISS (reais)	T	0.1	2.7	214	0.42
	C	−0.1	2.7	84	
Log State transfer – ICMS (reais)	T	3.5	2.3	214	−1.24
	C	3.8	2.0	84	
Log Federal transfer – FPM (reais)	T	4.2	1.5	214	−0.76
	C	4.3	1.4	84	

we mapped the changes between 1991 and 2010 and created an identifier to match new counties to their original territory. Then, we merged the new territories to their original one and applied the 1991 baseline county as our observation unit. We aggregated the variables of interest accordingly. This procedure leads to an additional problem because now we can have treated and not treated counties in the same territory. To deal with this additional problem, we weight the event-study and DD treatment dummy variables using the 2010 counties' territory as the weight. For example, if 60% of the territory of a county in 1991 becomes a separate 2010 county (where hydropower development took place), while the remaining 40% of the 1991 area became a non-treated county in 2010, the dummy variable value for the new treated county will be assumed to be 0.6.

4.2.4. Difference-in-differences

To evaluate the post-construction impacts from hydropower development on local socio-economic conditions, we selected eight variables (income, education, longevity, the percentage of public access to electricity and piped water, population density, HIV cases, and teenage pregnancy rates) to characterize the socio-economic dimensions of each county in 1991, 2000, and 2010.

For these analyses we use a difference-in-differences (DD) approach because data for the socio-economic indicators are only available every decade. The DD estimation strategy consists of identifying a specific intervention, then comparing the difference in the indices of interest before and after the intervention for the group affected by the treatment with the corresponding difference for the comparison group. In our case, the intervention is the beginning of the operation of hydropower plants. Again, the treatment group consists of counties that got hydropower and the control group consists of counties with plans to build hydropower that have not yet materialized. The DD approach has been widely used for policy evaluation (Meyer, 1995; Bertrand et al., 2004).

We cross-referenced the human development indices with the information organized by ANEEL about the Brazilian hydropower plants, creating a variable that identifies when hydropower plants started operating in each county. We classified the counties with hydropower reservoirs in two groups (see Table 4). The first treated group (Group A) contains 46 counties where hydropower operations began in the first period of analysis (1991–2000). The second treated group (Group B) contains 101 counties that started operations during the second period (2000 − 2010). As multiple plants affect some counties, we restricted the analysis for groups A and B for the counties that were not receiving WRFC funds from plants built before 1991. The treatment parameter is the year that the power plant starts generating electricity, so we are not including a specific assessment of the construction stage.

Eq. (7) defines the basic DD specification:

$$\text{Model 3}: \; HumanDevelopmentIndex_{it} = \psi_1(HP_i * T_t) + T_t + \alpha_i + \gamma_k Z_{k,it} + \epsilon_{it} \quad (7)$$

The dependent variable listed in Eq. (7) (*HumanDevelopmentIndex*) represents the indices selected for analysis, which include income, longevity, education, access to electricity and piped water, teenage pregnancy rates, and HIV cases. T is a dummy variable that identifies the post-construction period and controls for timing effects. We also separated the analysis in two periods: short term versus long term. The short term is the period between 1991 and 2000 for Group A, and 2000 to 2010 for Group B ($T = 1$ if year equals 2000 for Group A, and 2010 for Group B, respectively). The long term period is 1991 to 2010 ($T = 1$ if year equals 2010, with 2000 values excluded), and is observed only for Group A. *HP* is a dummy variable for each treated group (Group A and Group B) and controls for the time-invariant differences between control and treated counties. The interaction between *HP* and *T* defines the coefficient of interest ($\Psi 1$), which evaluates the effect of the hydropower plant on socio-economic indicators. We also control for county fixed effects with α_i. Recall that HP is incorporated by these county effects, therefore not included directly in the estimating equation. The Z_k matrix contains a list of control variables that include annual temperature and precipitation, and γ_k is the vector of regression coefficients from those control variables. e_{it} is the error term.

5. Results

In this section, we present two sets of results about how large hydropower plants have affected the socio-economic indicators in Brazil. First, we explore the impacts from hydropower development on the local GDP and public revenues. Then, we assess the robustness from GDP and public revenues results and their heterogeneity. Second, we examine how hydropower plants affect social variables: average income, life expectancy, educational level, access to piped water, access to public electricity, teenage pregnancy levels, and HIV cases.

5.1. Hydropower development and local economic activity

We assess the economic effects of hydropower construction and operation by comparing counties that built plants between 1991 and 2010 (treated) with counties that had plans to build hydropower but had not yet begun construction by 2010 (controls). Fig. 3 presents the results of the event-study analysis for the total GDP and its subcategories (industry, services, and agriculture).

In order to test the validity of the event-study approach, we look at the behavior of the outcome variable prior to hydropower development. The coefficients represent the time path of the GDP relative to the date when construction of a hydropower plant started (Kline, 2012). Except for one coefficient in agricultural GDP, there were no observable differences between treated and control groups before construction began, supporting the critical assumption that control and treated counties were on similar economic paths before hydropower development.

Fig. 3 shows that, during the construction period, treated counties had a greater average increase in total GDP than control counties. This growth is insignificant during the first two years, but achieves a peak in the third year after construction begins, when the average annual GDP growth is 10% (95% CI: 1% to 20%) larger than control counties. After this peak the GDP difference substantially decreases, although it does not fully return to pre-construction levels. During the construction

Table 4
Socioeconomic indicators sample statistics.

Socioeconomic indicators (1991)	Group A ($n = 46$) Mean	Standard deviation	Group B ($n = 101$) Mean	Standard deviation	Control group ($n = 84$) Mean	Standard deviation
Education	0.21	0.07	0.18	0.07	0.20	0.07
Longevity	0.57	0.05	0.54	0.08	0.68	0.05
Income	0.69	0.06	0.67	0.06	0.55	0.07
% of households with access to electricity	83	15	70	21	76	21
% of households with access to piped water	73	19	58	25	66	22
% teenage pregnancy	3.1	2.1	2.3	1.5	2.5	1.7
Number of HIV cases	3.9	16.1	3.4	21.3	1.9	10

and oper … n control

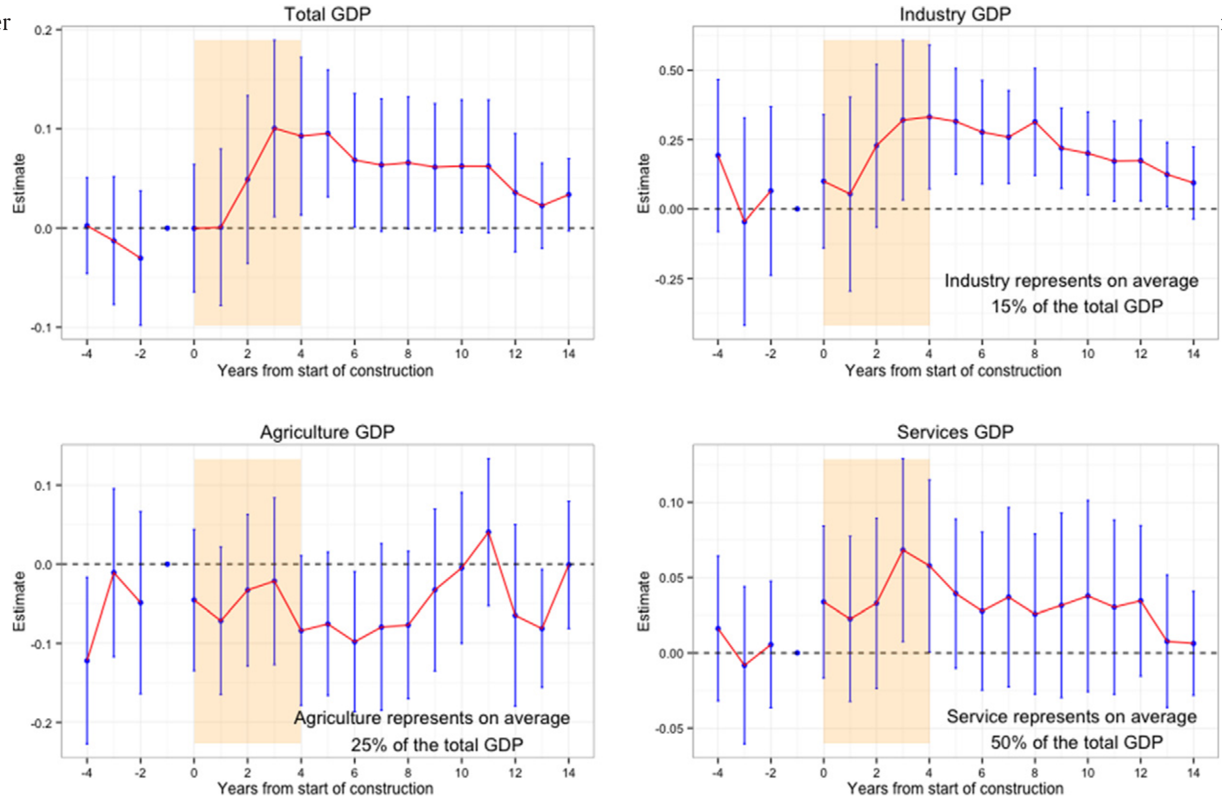

Fig. 3. Gross domestic product (GDP) event-study regression results. Titles refer to dependent variables. The y-axis represents the coefficient estimates (β_y's from Model 1 defined in the Methods section) for each gross domestic product indicator in log points. To obtain the results in percentage increase relative to the pre-construction period compute exp(*Estimate*) − 1. The x-axis describes the coefficient outcome in each year relative to the first construction year (Year 0). The light orange boxes represent the average period of hydropower plant construction from our database (approximately 4 years). Points represent the average effect and bars represents the 95% confidence intervals defined as two times the standard errors (robust standard errors are clustered at the county level and hydropower plant).

GDP is 4% (95% CI: −2% to 10%) and 5% (95% CI: 0% to 10%), respectively.

The increase in GDP is likely due to an increase in industrial GDP, which increases very fast a few years after the beginning of construction. Fig. 3 shows that, at the peak (4th year), hydropower development is associated with an industrial GDP increase of 39% (95% CI: 7% to 80%) per year compared to the pre-construction phase. However, 14 years after the start of construction this effect drops to an average of 9% (95% CI: −3% to 24%). A similar trend is observed in the services sector, where there is an increase of 7% (95% CI: 1% to 15%) in the third year with a gradual reduction thereafter.

In contrast, hydropower development is associated with a temporary loss in agricultural GDP. In the sixth year after construction begins, we observe a 10% reduction (95% CI: −3% to −18%) in agricultural GDP.

We also assess the relationship between hydropower development and public revenues in Fig. 4. Like the GDP, we do not observe differences in public revenues between treated and control groups before construction began. Public revenues increase an average of 6% (95% CI: 0% to 10%) after the beginning of construction, and continue to rise when operations start, achieving a peak (15%; 95% CI: 9% to 21%) eight years after construction begins. After the eighth year, however, public revenues return to pre-construction levels.

Fig. 4 also breaks down public revenue results by its main subaccounts: local services tax (ISS), state transfers (ICMS), and federal government transfers (FPM). The first increase in public revenue is associated with the growth in the local taxes. ISS revenues more than double during the construction period but their positive effects are limited to 11 years after construction begins.

The second growth in public revenues occurs because of the growth in state transfers. Average ICMS in treated counties start to increase in the sixth year achieving a peak in the eighth year when the state counties. State transfers return to pre-construction levels after the eleventh year. Finally, our analysis suggests a long-run negative trend on federal transfers to the county's budgets.

5.2. Sensitivity and heterogeneity

We assessed the sensitivity of our models to alternative specifications, including regressions without control variables and using alternative control groups. The removal of covariates did not affect the coefficients but increased the standard errors, suggesting that the control covariates help to explain part of the noise from our data. Furthermore, if we used all Brazilian counties that did not build hydropower plants as controls in our analysis, the effects of hydropower development are greater for GDP but lower for taxes, indicating that failing to control for natural advantages and siting decisions slightly biases the results. The SI also includes assumption checks (e.g. the strict exogeneity assumption, Wooldridge, 2004) and a residual analysis. These additional model tests and the sensitivity analysis qualitatively support our main findings.

We also evaluated the heterogeneity of hydropower development impacts by dividing the data along four dimensions: 1) larger (>500 MW) versus smaller plants (between 30 and 500 MW); 2) utility versus industrial ownership; 3) small (<30,000 people) versus large (>30,000 people) counties, and 4) more developed (those with human development index > 0.4 in 1991) versus less developed counties (human development index < 0.4).

We find that smaller hydropower plants perform better in terms of GDP and tax revenues than larger plants. Fig. 5 shows that the greater negative impact from larger plants in the agriculture GDP likely explains the difference between smaller and larger plants. We also find that counties where industry facilities and hydropower were simultaneously

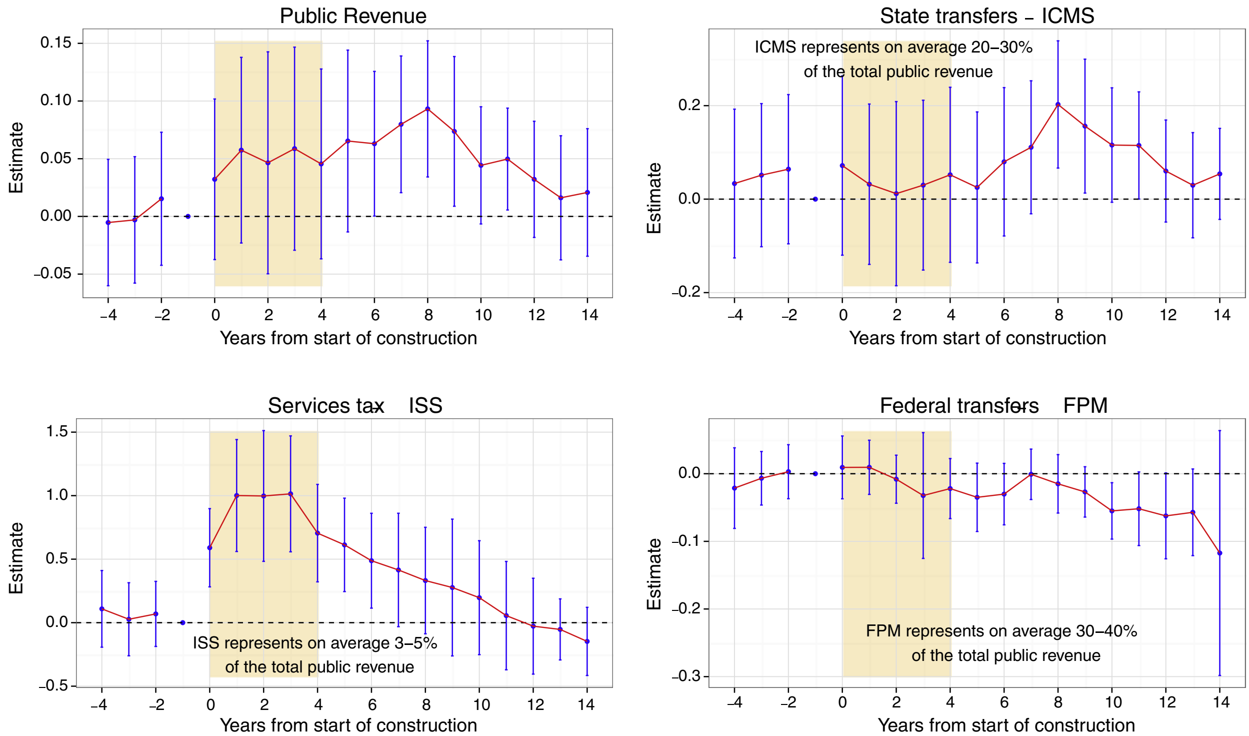

Fig. 4. Public revenue event-study regression results. Titles refer to dependent variables. The y-axis represents the coefficient estimates (β_y's from Model 1 defined in the Methods section) for each revenue indicator in log points. To obtain the results in percentage increase relative to the pre-construction period compute (exp(*Estimate*) − 1). The x-axis describes the coefficient outcome as function of the years from beginning of the construction (Year 0). The light orange boxes represent the average period of construction of the hydropower plants from our database (approximately 4 years). Points represent the average effect and error bars represent the 95% confidence intervals defined as two times the standard errors (robust standard errors are clustered at the county level and hydropower plant level).

constructed have greater tax and GDP revenues than those without such involvement from the industry (see Figs. S4 and S5, SI). Industry-owned projects are likely developed to supply electricity to industries like mining and aluminum manufacturing, which contribute to industrial GDP. Those electro-intensive industries build power plants close to their facilities to ensure a steady supply of electricity. Additionally, our results suggest that small counties were significantly affected by hydropower development while larger counties are barely affected (see Figs. S6 and S7, SI). We don't find a clear distinction between hydropower effects on more or less developed counties (see Figs. S8 and S9, SI). The SI contains the detailed results and discussion about heterogeneity.

5.3. Hydropower development and socio-economic indicators

We applied a difference-in-differences estimation strategy to estimate the effects of hydropower projects on human development indicators and other outcomes of interest. Fig. 6 depicts the estimated coefficients for our three human development indicators as well as the other variables of interest. The regression results indicate that the socio-economic indicators for counties that built hydropower plants were not significantly different (either in the short or long run) from counties in the control group. As in previous studies, we do not observe population agglomeration (Severnini, 2014).

For education, access to piped water and electricity, and teenage pregnancy we cannot determine whether the relationship was negative or positive. The indication of negative effects on access to piped water and electricity could be explained by the growth in irregular housing. During the construction boom, local inflation may rise, increasing housing prices and rental rates. As a consequence, low-income families may be displaced to more distant places without electricity and piped water infrastructure.

Our results also suggest that the WRFC policy has not been effective in improving socio-economic conditions relative to group of counties that did not receive such payments, our control group in this context. The SI includes an additional analysis where we assess the socio-economic impacts of the WRFC policy alone. Specifically, we evaluate 379 counties affected by hydropower plants in operation before 1991 that started receiving WRFC funds only in 1991, when the compensation policy was put into effect. The WRFC implementation represents a discontinuity for the treatment group and allows us to investigate the effect of the WRFC alone, excluding the construction effect. We find that WRFC policy is associated with relative deterioration of socio-economic indicators (e.g., income and life expectancy) in the long run (see Fig. S10, SI).

6. Discussion

This study examines the relationship between socio-economic indicators and hydropower development in Brazil between 1991 and 2010. We apply event-study and difference-in-differences panel econometric methods to remove time-invariant unobserved confounders and capture the time-course of development impacts relative to control counties that had plans to build hydropower plants, but had not yet built them. We have four main findings: 1) hydropower plant development increases total, industrial, and services GDP (with peaks in the 3rd or 4th year) and decreases agricultural GDP (with nadir in the 6th year), followed by a return to levels around the pre-construction levels in the long run, 2) public revenues follow a similar pattern with a long-term negative trend on federal tax transfers, 3) smaller hydropower plants generate larger positive impacts than larger plants in terms of GDP and tax revenue, and 4) there are no observable impacts on socio-economic indicators, and the WRFC has either no or negative impact.

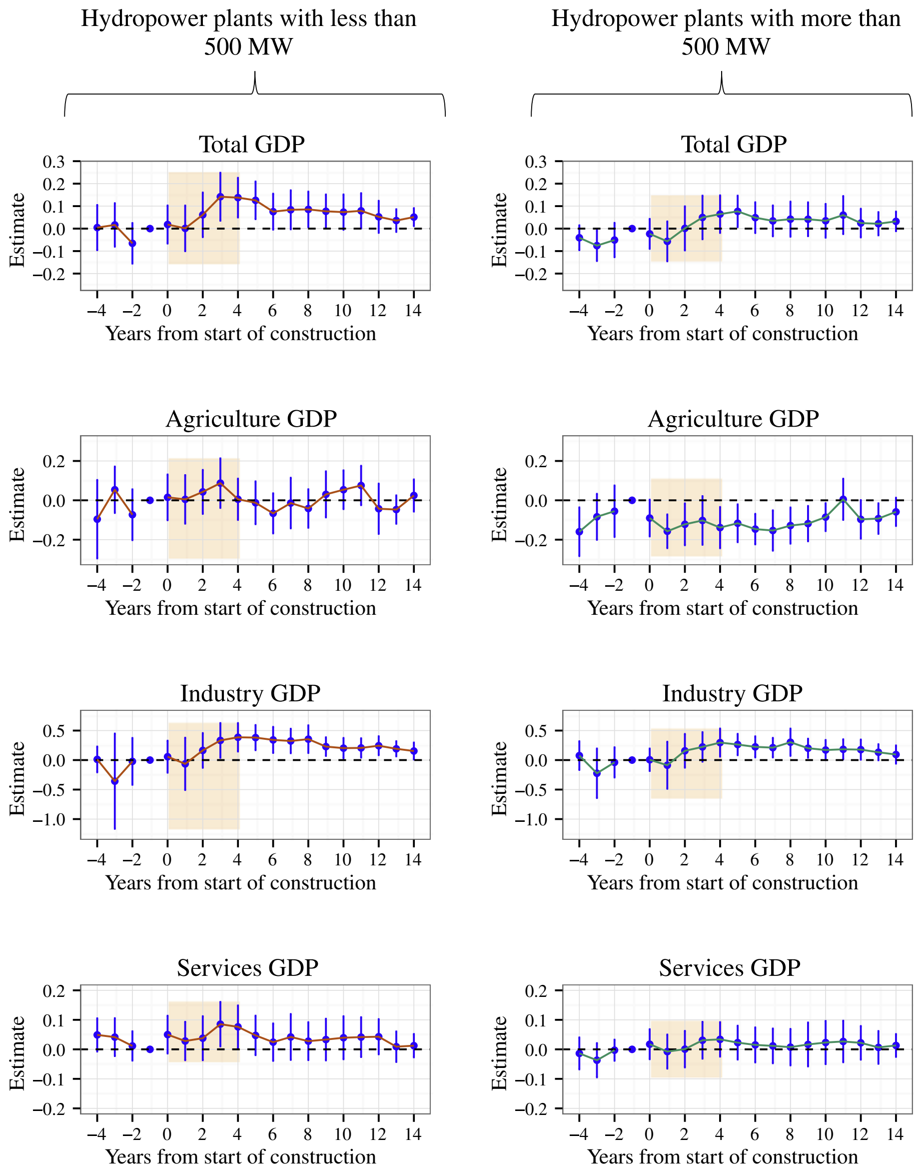

Fig. 5. Smaller (<500 MW of installed capacity) versus larger hydropower plants (>500 MW of installed capacity): gross domestic product event-study regression results. Titles refer to dependent variables. The y-axis represents the coefficient estimates (β_y's from Model 1 defined in the Methods section) for each gross domestic product indicator in log points. To obtain the results in percentage increase relative to the pre-construction period compute exp(*Estimate*) − 1. The x-axis describes the coefficient outcome in each year relative to the first construction year (Year 0). The light orange boxes represent the average period of hydropower plant construction from our database (approximately 4 years). Points represent the average effect and bars represents the 95% confidence intervals defined as two times the standard errors (robust standard errors are clustered at the county level and hydropower plant).

We first discuss the internal validity of the results, and then discuss each finding in the light of the Brazilian context and prior work.

Concerning the internal validity of the results, although our framework allows us to test the assumption that treated and control counties have similar economic pathways before construction, there may still be unobserved differences between counties with and without hydropower plants. The main concern is that the control group may consist of counties that are less attractive for hydropower development due to factors also related to their socio-economic indicators, leading to bias in our estimates. For example, investors could be more eager to build hydropower plants close to existing transmission lines to reduce construction costs, and those lines could be in more dense or developed areas.

Although we control for many of these issues using fixed effects, covariates, and selecting control counties in the same geographical areas as treated counties, there is always a potential for bias. However, we believe that these confounding issues are a low risk for two reasons. First, counties are selected based on project feasibility rather than current and projected local socio-economic conditions. Second, most of the control group counties that have plans to develop hydropower face a long regulatory process. Projects are rarely suspended or canceled, and when that happens it is usually not because of socio-economic conditions. For example, suspended projects are often waiting for regulatory decisions or a new master plan review. The only canceled project was stopped for environmental restrictions.

Our first main result is that hydropower plant development temporarily increases total, industrial, and services GDP but decreases agricultural GDP (Fig. 3). This latter result is consistent with previous work that also observed a short-term decrease in agricultural production around Brazilian dams (Lipscomb et al., 2013). Decrease in agricultural GDP likely results from two factors. First, reservoir development requires flooding available land that would otherwise be used for agricultural production and fishing resources. Second, new opportunities in the services and industrial sectors likely deprive the agricultural sector

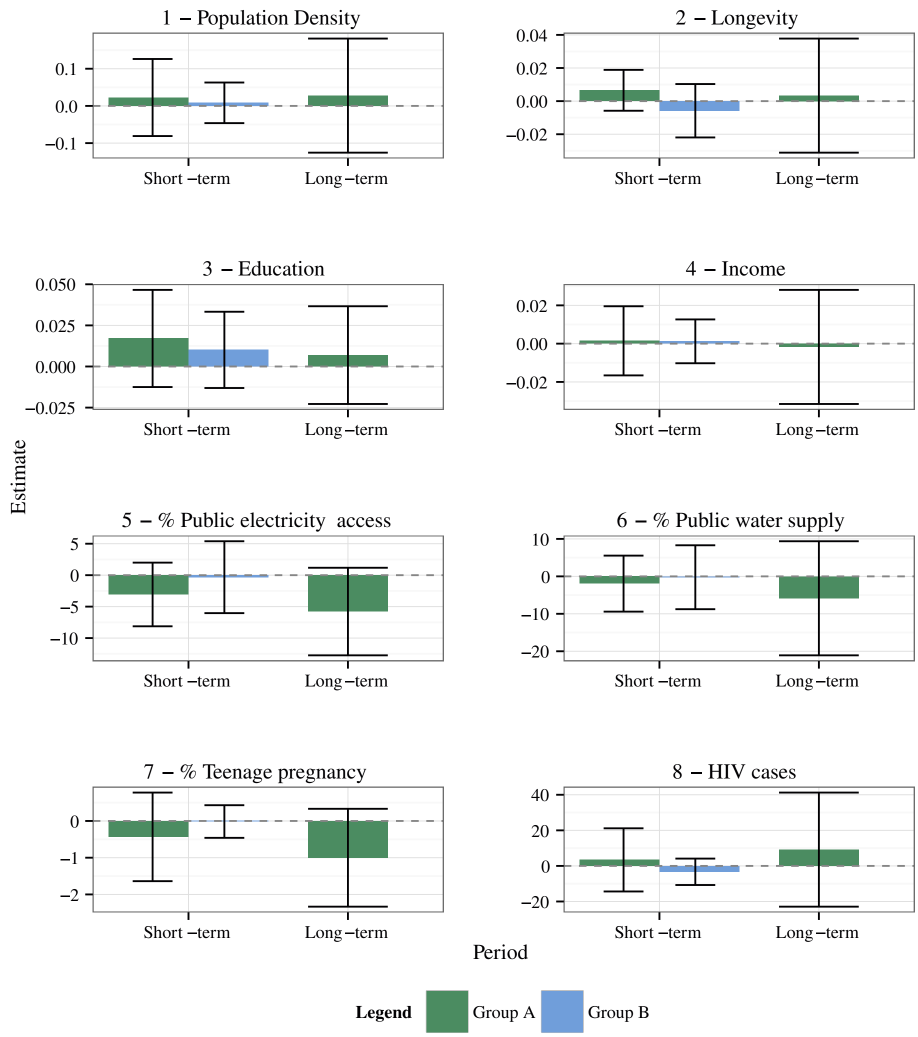

Fig. 6. Difference-in-differences regression results for the human development indicators and other outcomes of interest for A and B treatment groups (described in the Methods section). Bars represent the average ψ_1 coefficient estimates from Eq. (7) described in the Methods section. Error bars represent the 95% confidence intervals defined as two times the standard errors (robust standard errors are clustered at the county level and hydropower plant level). Short term represents the first decade after hydropower development (A: 1991–2000 and B: 2000–2010). Long term represents two decades after hydropower development (only A: 1991–2010).

from workers. Further, total GDP results show that the boost in local economic activity due to hydropower development is limited to the construction years and first few years of operation, suggesting new investments are not attracted to the region and that the majority of dam workers likely leave affected counties. Those results are consistent with the history of infrastructure projects in Brazil, where dam workers, popularly known as *barrageiros*, are known for constant migration around the country from one dam construction to another (Quintella, 2008).

Our second result is that public revenues increases, but only for a limited time (Fig. 4). Local services tax revenues (ISS) increase during the construction period because of the higher demand for local goods and services, but this growth is temporary and ISS revenues return to pre-construction levels in the twelfth year. ISS trajectory is consistent with Pathway 3 (Fig. 1) indicating that local economic activity carries some momentum from the dam construction, but workers and new business slowly leave the region because of the lack of new opportunities or investments.

Regarding the hydropower development impact on state transfers (ICMS), growth occurs during the first few years of operation because the proportion of the ICMS received by each county varies by state and is a function of the county's GDP. As the treated counties' GDP increases due to the construction and operation of the power plants, the ICMS transfers to those counties also grow. Like the total GDP, ICMS transfers increase only for a limited period of time. The delay between GDP and ICMS curves occurs because states apply GDP information from the previous years to define ICMS transfers in the current year.

Our results also suggest a decreasing trend on federal transfers. FPM distribution relies on complex criteria that include the size of the population and the state where the county is located. FPM transfers can decrease for a given county if 1) the share of federal resources to other counties in the state increases in relation to total amount of resources available, 2) the county population decreases, or 3) new counties are created in the state (Ministerio da Fazenda and S. do Tesouro Nacional, 2013).

The ISS, ICMS, and FPM results indicate that there is only a short-term increase in tax revenue to counties affected by hydropower plants. Because electricity can be transmitted to long-distances, our outcomes emphasize that the tax structure is a relevant driver to define allocation of benefits between hydropower producing regions and places with high electricity demand. Therefore, both public revenues and GDP results point to the same direction and suggest that hydropower development in Brazil does not lead to long-term increase in the local economic activity.

Our third result is that counties affected by smaller hydropower plants have more positive local impacts than counties affected by bigger projects. We observe that smaller plants did not negatively affect the agricultural GDP (Fig. 5) while larger plants were associated with substantial reductions in agricultural GDP. Those results likely occur because of the distinct magnitude of the reservoir areas as smaller hydropower plants often require less flooded area than larger ones.

Finally, the absence of long-term effects on local economies likely explains the lack of long-term positive social impacts (Fig. 6). Our results differ from the positive effects from electrification found in Brazil (Lipscomb et al., 2013). Using county-level data from 1960 to 2000 in Brazil, Lipscomb et al. (2013) found large and positive effects of electrification on local human development index as well as in other socio-economic variables such as employment, salaries, and investments in education. This difference likely happens because of the distinctive spatial and temporal emphasis in our paper, which focuses only in the counties directly affected by the dam construction during the first years of operation, and theirs, which assesses the long-term effects from electrification across all counties.

7. Policy implications

In this paper we have provided evidence that the effects of hydropower projects on local economies in Brazil are the result of two cycles: construction and operation. We found, however, that most of those effects are short-lived, and disappear in <15 years. This is particularly important because large hydropower dams (and their environmental consequences) last many decades or even centuries. Additionally, we did not find evidence that hydropower development contributes to long-term improvement of local social indicators. Hence, the empirical evidence does not support long-term positive economic and social impacts described in the environmental impact assessments for Brazilian projects. Our results highlight the need for empirically driven methods to assess the socio-economic viability of hydropower development in Brazil. We acknowledge, however, that this paper focuses only on the local effects associated with site construction and does not evaluate the overall effects of the electricity transmitted to other parts of the Brazilian economy, which may in fact be more positive that our local results suggest.

This work also brings new empirical evidence to the debate about financial incentives for infrastructure and energy projects. Often, state and local governments use tax exemptions, subsidies, and changes in tax structure to try to attract industry and thus promote regional growth (Morgan and Hackbart, 1974). The quick reversion of local economic activity to levels slightly above pre-construction levels in Brazilian counties affected by hydropower plants relative to control counties suggests that current policies aimed at spurring hydropower development to support local well-being may not be effective.

8. Conclusion

Hydropower development in Brazil results in a short-term boom and long-term trickle of economic activity for counties surrounding hydropower plants, and little to no improvement in socio-economic conditions. Rather than facilitating long-term development and synergy between co-located industries and workers that attract new development and investment, workers and new business gradually leave the region. The results empirically question justifications for hydropower development based on expectations of long-term economic and social development, and provide insights into potential taxation mechanisms and policy programs that may help counties affected by hydropower plants to materialize better socio-economic conditions.

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Competing financial interests

The authors declare no competing financial interests.

Appendix A. Supplementary data

This manuscript includes a supporting information document, which includes detailed descriptions of the methods employed, as well as additional results and references. Supplementary data associated with this article can be found in the online version, at http://dx.doi.org/10.1016/j.eneco.2017.08.035.

References

ANEEL — Agencia Nacional de Energia Eletrica (Brazilian Electricity Agency), 2015e. Water resources use financial compensation data.
ANEEL — Agencia Nacional de Energia Eletrica (Brazilian Electricity Agency), 2015e. Sistema de informações georreferenciadas do setor elétrico - SIGEL.
ANEEL — Agencia Nacional de Energia Eletrica (Brazilian Electricity Agency), 2016e. Generation Information Databank (BIG — Banco De Informações De Geração — Aneel).
Ansar, A., Flyvbjerg, B., Budzier, A., Lunn, D., 2014. Should we build more large dams? The actual costs of hydropower megaproject development. Energ. Policy 69, 43–56.
Bertrand, M., Duflo, E., Mullainathan, S., 2004. How much should we trust differences-in-differences estimates? Q. J. Econ. 119, 249–275.
Brown, P.H., Tullos, D., Tilt, B., Magee, D., Wolf, A.T., 2009. Modeling the costs and benefits of dam construction from a multidisciplinary perspective. J. Environ. Manag. 90, S303–S311.
Duflo, E., Pande, R., 2007. Dams. Q. J. Econ. 122, 601–646.
Egré, D., Milewski, J.C., 2002. The diversity of hydropower projects. Energ. Policy 30, 1225–1230.
Eletrobras, 2009. Relatório de Impacto Ambiental UHE Belo Monte. Eletrobrás.
Eletrobras, 2014. AHE São Luiz Do Tapajós. Eletrobrás.
EPE, 2010a. Relatorio de Impacto Ambiental UHE Teles Pires. Empresa de Pesquisa Energetica (EPE).
EPE, 2010b. Relatório de Impacto Ambiental UHE Sinop. Empresa de Pesquisa Energetica (EPE).
EPE, 2011. Relatório de Impacto Ambiental UHE São Manoel. Empresa de Pesquisa Energetica (EPE).
Fearnside, P.M., 2001. Environmental impacts of Brazil's Tucurui Dam: unlearned lessons for hydroelectric development in Amazonia. Environ. Manag. 27, 377–396.
Fearnside, P.M., 2006. Dams in the Amazon: Belo Monte and Brazil's hydroelectric development of the Xingu River Basin. Environ. Manag. 38, 16–27.
Fearnside, P.M., 2015. Tropical hydropower in the clean development mechanism: Brazil's Santo Antônio dam as an example of the need for change. Clim. Chang. 131, 575–589.
Feyrer, J., Mansur, E.T., Sacerdote, B., 2015. Geographic Dispersion of Economic Shocks: Evidence from the Fracking Revolution. pp. 1–48.
Friedl, G., Wuest, A.A., 2002. Disrupting biogeochemical cycles — consequences of damming. Aquat. Sci. 64, 55–65.
Furnas, Odebrecht, Leme, 2008. Estudos de Impacto Ambiental das UHEs Jirau e Santo Antonio. pp. 1–191.
Greenstone, M., Hornbeck, R., Moretti, E., 2010. Identifying Agglomeration Spillovers: Evidence from Million Dollar Plants. J. Polit. Econ. 118 (3), 536–598.
Hug-Glanzmann, G., 2011. A hybrid approach to balance the variability and intermittency of renewable generation. 2011 IEEE PES PowerTech — Trondheim. IEEE, pp. 1–8.
I. de Pesquisa Economica Aplicada IPEA, 2015. IPEADATA.
I.B. de Geografia e Estatística IBGE, 2016. Instituto Brasileiro de Geografia e Estatística (IBGE).
Intergovernmental Panel on Climate Change (IPCC), 2011. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. IPCC.
Jackson, S., Sleigh, A., 2000. Resettlement for China's Three Gorges Dam: socio-economic impact and institutional tensions. Communis. Post-Commun. Stud. 33, 223–241.
Jacobson, L.S., LaLonde, R.J., Sullivan, D.G., 1993. Earnings losses of displaced workers. Am. Econ. Rev. 83, 685–709.
Kline, P., 2012. The impact of juvenile curfew laws on arrests of youth and adults. Am. Law Econ. Rev. 14, 44–67.
Kline, P., Moretti, E., 2014. Local economic development, agglomeration economies, and the Big Push: 100 years of evidence from the Tennessee Valley Authority. Q. J. Econ. 129, 275–331.
Koch, F.H., 2002. Hydropower—the politics of water and energy: introduction and overview. Energy Policy 30, 1207–1213.
Lerer, L.B., Scudder, T., 1999. Health impacts of large dams. Environ. Impact Assess. Rev. 19, 113–123.
Lipscomb, M., Mobarak, A.M., Barham, T., 2013. Development Effects of Electrification: Evidence from the Topographic Placement of Hydropower Plants in Brazil. Am. Econ. J. Appl. Econ. 5 (2), 200–231.
Manyari, W.V., de Carvalho Jr, O.A., 2007. Environmental considerations in energy planning for the Amazon region: downstream effects of dams. Energy Policy 35, 6526–6534.

McCrary, J., 2007. The effect of court-ordered hiring quotas on the composition and quality of police. Am. Econ. Rev. 97, 318–353.
Meyer, B.D., 1995. Natural and quasi-experiments in economics. J. Bus. Econ. Stat. 12, 42.
Ministerio da Fazenda, S. do Tesouro Nacional, 2013. Cartilha - Fundo de Participação dos Municípios – FPM. Brazilian government.
Ministério da Saúde, 2016. DATASUS.
Morgan, W.E., Hackbart, M.M., 1974. An analysis of state and local industrial tax exemption programs. South. Econ. J. 41, 200.
Newell, R.G., Raimi, D., 2015. Shale Public Finance: Local Government Revenues and Costs Associated with Oil and Gas Development. National Bureau of Economic Research, pp. 1–87.
Quintella, W., 2008. Memórias do Brasil grande: a história das maiores obras do país e dos homens que as fizeram.
Rosenberg, D.M., Bodaly, R.A., Usher, P.J., 1995. Environmental and social impacts of large scale hydroelectric development: who is listening? Glob. Environ. Chang. 5, 127–148.
Rosenberg, D.M., Berkes, F., Bodaly, R.A., Hecky, R.E., Kelly, C.A., Rudd, J.W.M., 1997. Large-scale impacts of hydroelectric development. Environ. Rev. 5, 27–54.
Rosenthal, S.S., Strange, W.C., 2004. Evidence on the nature and sources of agglomeration economies. Handbook of Regional and Urban Economics.
S. do Tesouro Nacional, 2010. County Public Budget Data from the Brazilian Counties.
Severnini, E.R., 2014. The Power of Hydroelectric Dams: Agglomeration Spillovers. Institute for the Stufy of Labor (IZA), pp. 1–70.
da Silva Soito, J.O.L., Freitas, M.A.V., 2011. Amazon and the expansion of hydropower in Brazil: vulnerability, impacts and possibilities for adaptation to global climate change. Renew. Sust. Energ. Rev. 15, 3165–3177.
Sovacool, B.K., Bulan, L.C., 2011. Behind an ambitious megaproject in Asia: the history and implications of the Bakun hydroelectric dam in Borneo. Energy Policy 39, 4842–4859.
Von Sperling, E., 2012. Hydropower in Brazil: overview of positive and negative environmental aspects. Energy Procedia 18, 110–118.
Tilt, B., Braun, Y., He, D., 2009. Social impacts of large dam projects: a comparison of international case studies and implications for best practice. J. Environ. Manag. 90, S249–S257.
U.N.D.P. UNEP, Instituto de Pesquisa Econômica Aplicada IPEA, Pinheiro, F.J., 2015E. Brazil's human development atlas (Atlas do desenvolvimento humano no Brasil).
Wooldridge, J.M., 2004. Econometric Analysis of Cross Section and Panel Data.