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Abstract

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Keywords

electricity availability, electricity consumption, economic growth, development economics

JEL Classification

O47, Q43, Q48

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Electricity availability: A precondition for faster economic growth?

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1. Introduction

The human welfare consequences of economic growth are staggering (Lucas, 1988), meaning that identification of factors able to encourage economic growth is one of the key focuses of macroeconomic research. Many factors have been found to contribute to faster economic growth, including macroeconomic and political stability, health and education investment, effective institutions, trade openness, geographical conditions, and favorable conditions for private enterprise (Sala-i-Martin, 1997; Perkins et al., 2013).[1] Whether the list of growth determinants includes electricity availability is the question that we pose in this paper.

The importance of this question is evidenced by, for example, the commencement of a major research programme exploring the links between energy and economic growth funded by the UK's Department for International Development (Oxford Policy Management, 2016). The World Bank has also shown substantial interest in assessing the contribution of electricity availability to economic development (Bacon and Kojima, 2016). The United Nations Sustainable Development Goal 7 includes a sub-goal of achieving universal access to modern energy for all.

We start our analysis by defining electricity availability in general terms to capture multiple aspects of electricity: the quantity of electricity consumed, the quantity of electricity consumed by the industrial sector, generation capacity, residential access rate, and quality of electricity supply. Electricity consumption is often the focus of studies on the relationship between electricity and economic growth, but assessing the effects of other components of electricity availability helps to give a more holistic picture. Electricity quality is a particularly topical aspect of electricity availability in many countries, as blackouts and voltage spikes can bring large economic costs to individual households and enterprises.

Our paper has a broad international focus, with a specific emphasis on developing countries (defined as low- and middle-income countries according to the World Bank classification in 2006). 2006 is the starting point for our initial cross-sectional decadal analysis. We produce estimation results for both a developing country sample and the broader global group.

Electricity availability rates are low in some developing countries; over a billion people did not have residential access to electricity in 2014 (World Bank, 2017a). In Nigeria, approximately 75 million people, or 40 percent of the population, went without electricity.

[1] Macroeconomic stability relates to aspects such as inflation, budget deficits, exchange rates, and capital flows.

Per capita electricity consumption in Ethiopia is less than 0.5 percent of the level in the United States (US), or less than US per capita electricity consumption for decorative seasonal lights (Center for Global Development, 2015; World Bank, 2017a).

Electricity is an important factor of production for many production processes (Stern 2011), with substitutability of electricity for other inputs often being somewhat limited. Electricity also attracts substantial policy interest for a number of reasons: electricity transmission infrastructure displays natural monopoly characteristics; the private sector often baulks at investing in electricity infrastructure in rural areas; and there are long time-frames involved in building some types of electricity infrastructure (Stern et al., 2017a).

The importance of various factors of production for economic performance could differ over time and place. For instance, Stern and Kander (2012) found that energy-augmenting technological change was important for economic growth in the 19th and early 20th century in Sweden, prior to labor-augmenting technological change becoming the dominant contributor. On the other hand, enclave activities such as mining and oil extraction are not likely to rely on widespread energy access across a population. These activities represent sizeable shares of gross domestic product (GDP) in some developing countries.

In addition to being a direct factor of production, electricity availability may also indirectly boost economic growth. One indirect channel could be by facilitating physical capital accumulation (Lechthaler, 2017). Electricity access can also help to reduce household air pollution and adverse health impacts from solid fuel use (Lim et al., 2012), which could lead to healthier and more productive workers. Electricity availability provides benefits from improved lighting at night, and from allowing households to reduce the time they spend collecting fuelwood (World Bank, 2010). In addition, electricity may also contribute to economic growth through an employment channel, by allowing people to increase the number of hours they can spend on productive activities (Salmon and Tanguy, 2016).

Most previous papers on the electricity-growth relationship have focused on short-run effects. The main contribution of this paper is that, in contrast, we consider the impact of multiple dimensions of electricity availability on subsequent economic growth over a *decadal* horizon. Our use of a decadal window is better able to identify medium-run effects.

The remainder of the paper is set out as follows. Section 2 reviews the existing literature on electricity availability and economic growth. Section 3 introduces our method and data. Our method utilizes decadal data rather than the annual data often employed in prior studies. Section 4 presents our results. The final section concludes.

2. Existing literature

There has been substantial research interest in the short-run relationship between electricity consumption and economic growth. Existing studies primarily use annual data and methods related to Granger causality and co-integration. The literature finds mixed results. Payne (2010) found that 23 percent of surveyed primary studies show a one-way relationship from electricity consumption to economic growth, 18 percent find a bi-directional causal relationship, while the rest find either a one-way relationship from economic growth to electricity consumption or no relationship. Ozturk (2010) found that the direction of causality differs between studies. Chen et al. (2012) note that researchers more commonly find that electricity causes output in OPEC and Kyoto Annex I countries, but the reverse direction of causation for developing countries.

Among more recent studies, Bruns et al. (2014) found an effect from output to energy use when energy prices are controlled for, rather than from energy to output. Kalimeris et al. (2014) found that each of the four causal relationships – energy or electricity causing economic outcomes, economic output causing energy outcomes, no relationship, and a bi-directional relationship – occurs in the literature about as often, and did not find systematic correlation between any causal pattern and the methodological approach. Of the 686 specifications included in the meta-analysis by Kalimeris et al. (2014), 168 are for electricity. Menegaki (2014) concluded that methodology, number of countries, and inclusion of variables such as the price level have an influence on Granger causality results for the energy-GDP relationship.

Another strand of literature focuses on the impact of infrastructure, including electricity infrastructure, on economic growth. Cross-country studies include one by Calderón and Servén (2010), who found a positive impact of infrastructure quality and quantity indicators on long-run economic growth. Calderón et al. (2015) found a long-run output elasticity with respect to a synthetic infrastructure index of between 0.07 and 0.1, while Kodongo and Ojah (2016) found that changes in an infrastructure index are positively associated with economic growth in Sub-Saharan Africa. In sub-national studies, Urrunaga and Aparicio (2012) found that infrastructure is important in explaining regional output differences in Peru, while Rud (2012) considered the importance of electricity for higher manufacturing output in India.

Identifying the causal effect of electricity availability on economic growth is a challenging empirical exercise. Identification issues arise from possible mutual causation, omitted variables, lagged effects of unknown and varying length, and a tendency for convergence over time in both the dependent and explanatory variables across countries. Granger causation and co-integration techniques, as used by much of the existing literature, are sensitive to variable definition, time period, choice of controls, sample size, and the introduction of structural breaks (Stern and Enflo, 2013). The focus of Granger causality studies is on year-to-year fluctuations, with the potential for substantial noise in the data. Some previous studies do not control for key growth determinants, leaving them exposed to omitted variables bias (a point also made by Payne (2010) and Bacon and Kojima (2016)). The list of potentially important omitted variables includes openness to trade, temperature, and availability of other energy types. It is also important to consider convergence processes when modelling economic growth (Barro, 1991, 2015).

Figure 1 gives an idea of the econometric challenge faced when attempting to determine causation using annual data: growth in electricity use per capita and in GDP per capita in China have been closely linked. Even powerful econometric methods may struggle to determine robust causal relationships in such a setting.

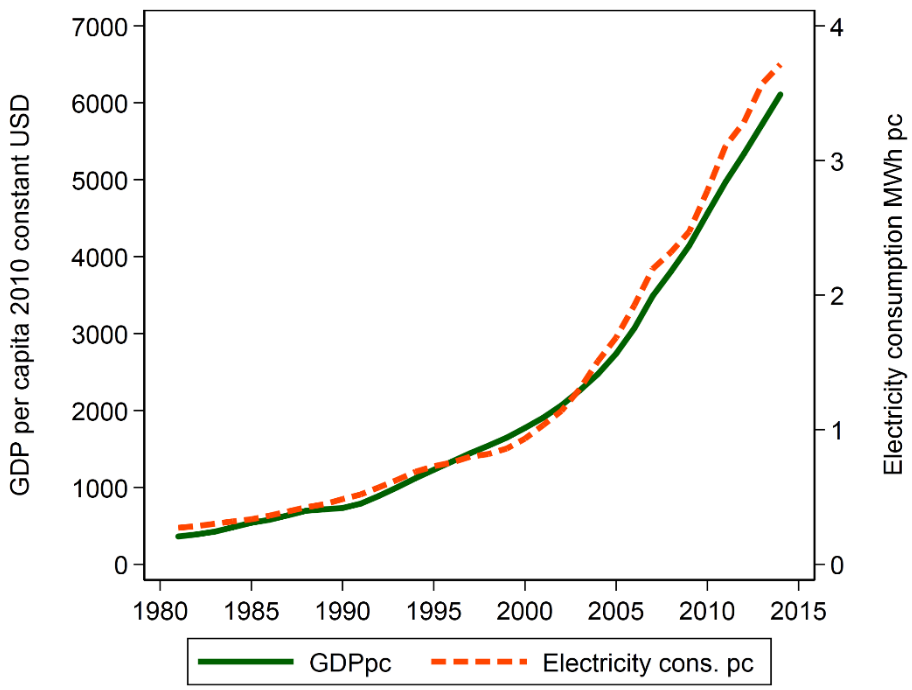

Figure 1. Electricity consumption per capita (megawatt hours) and GDP per capita (2010 constant US dollars) for China. Sources: US EIA (2017), World Bank (2017b).

3. Method and data

Instead of pursuing Granger causality or related approaches with annual data, in this paper we take an alternative approach of focusing on the effects of initial electricity availability measures on subsequent economic growth over a decadal horizon, while controlling for other potential determinants of economic growth. We first use a cross-sectional regression approach and then panel data, both using a dependent variable representing the average GDP growth rate over a decadal time horizon. Our approach shares similarities with the long-run differences approaches used in different contexts by Chirinko (2011), Burke and Csereklyei (2016), and Stern et al. (2017b).

We start by considering electricity as an argument in an aggregate production function. This is similar to including energy as an input to the aggregate production function, as done by Bretschger (2015). Starting from a production function at time *t* with electricity inputs (*E*) and non-electricity inputs (*N*) at a lag of *T* years:

$$Y_t = F(E_{t-T}, N_{t-T}) \qquad (1)$$

The non-electricity inputs in a standard production function would include endogenous factors such as labor and capital. In keeping with much of the growth determinants literature, we focus on underlying factors. For example, temperature is an exogenous geographical factor that may influence output levels. Other deep drivers of economic activity may include governance, trade openness, macroeconomic stability, and human capital variables.

Writing output as a Cobb-Douglas function of electricity and non-electricity inputs, as well as a catch-all “other” term (*A*):[2]

$$Y_t = A_t {E_{t-T}}^{\alpha} {N_{t-T}}^{\beta} \qquad (2)$$

Taking the log of both sides gives:

$$\ln Y_t = \ln A_t + \alpha \ln E_{t-T} + \beta \ln N_{t-T} \qquad (3)$$

We subtract lagged log GDP per capita from both sides, and then divide by T, the number of years, giving the model describing economic growth in equation (4). The parameters differ to those in equation (3) due to the transformation described in this paragraph.

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[2] The production function in equation (2) is also a constant elasticity of substitution production function with an elasticity of substitution of one.

$$(\ln Y_t - \ln Y_{t-T})/T \; = \; \ln A_t/T + \varphi \ln E_{t-T} + \gamma \ln N_{t-T} \; - \ln Y_{t-T}/T \tag{4}$$

To assess the impact of electricity availability on subsequent per-capita economic growth, we first use the cross-sectional regression approach in equation (5). All right-hand side variables are initial values (i.e. measured in year $t - T$). Our reason for first focusing on economic growth over the decade to 2016 is that there is greater data availability for some electricity variables for recent years. We also introduce flexibility in the coefficient for initial log GDP per capita so as to allow estimation of a GDP per capita convergence effect (Barro, 1991, 2015).

$$(\ln Y_c^{2016} - \ln Y_c^{2006})/10 \; = \; \alpha + \varphi \ln E_c^{2006} + \; \gamma \boldsymbol{x'}_c^{2006} + \; \lambda \ln Y_c^{2006} + \varepsilon_c \tag{5}$$

The dependent variable is the average annual rate of economic growth, calculated by differencing the logged variables and dividing by the number of years. The Y_c variable is GDP per capita for each of the countries (*c*). Note that our electricity variables are in effect measuring the impact of electricity intensity, defined as electricity per unit of GDP, since the initial level of log GDP per capita is included as a control.

A feature of our study is that we employ multiple measures of electricity availability (*E*), including both quantity and quality measures. These include total electricity consumption and generation capacity, and also electricity consumption by the industrial sector. Electricity is an important input to production in the industrial sector. In contrast, causation may run more strongly in the direction of income to electricity consumption quantity in the residential context, as found by Joyeux and Ripple (2011). We also analyze the effects of electricity transmission and distribution losses, a form of inefficiency, and the proportion of households that have residential access to electricity. Our quality measure is the electricity quality index of the World Economic Forum (2016), which is based on survey responses from business executives. Countries with low scores are those that experience blackouts and other quality issues, such as voltage spikes. The World Economic Forum quality measure has the advantage of being available for a large sample of countries. Table 1 provides details on the electricity variables and data sources.

Table 1. Dimensions of electricity availability

Variable	Source	Description
Log of electricity consumption per capita	EIA, WDI	Log of the quotient of total electricity consumption in billion kilowatt hours from EIA and total population from WDI.
Log of electricity capacity per capita	EIA, WDI	Log of the quotient of total electricity installed capacity in million kilowatts from EIA and total population from WDI.
Log consumption of electricity by industry per capita	IEA, WDI	Log of the quotient of electricity consumption by industry, in kilograms of oil equivalent from IEA, and total population from WDI.
Electricity transmission and distribution losses	WDI	Electric power transmission and distribution losses, as a percentage of electricity output divided by 100. Includes losses in transmission between sources of supply and points of distribution, and in distribution to consumers, including pilferage.
Access to electricity	WDI	Household access to electricity (percentage of population divided by 100).
Electricity quality index	WEF	Quality of electricity supply (lack of interruptions and lack of voltage fluctuations), 1=extremely unreliable, 7=extremely reliable.

Notes. Sources: EIA: U.S. Energy Information Administration (2017), IEA: International Energy Agency (2017), WDI: World Bank (2017b) World Development Indicators, WEF: World Economic Forum (2016).

Our $\boldsymbol{x}$ vector includes inflation, log life expectancy, an education index, governance variables, trade openness, log per capita consumption of energy sources other than electricity (in oil equivalent terms), and temperature. These variables are all measured at the initial year of the decadal growth period. We also consider regional binary variables, following the advice of Rockey and Temple (2016). Important impacts of unobservable factors such as technology differences (Eberhardt and Teal, 2011) can be partly controlled for by regional binary variables. Many of the explanatory variables are from the World Bank's (2017b) World Development Indicators. The governance variables are from the World Bank's (2016) Worldwide Governance Indicators. The education index is from the United Nations Development Programme (2016), and temperature is from the UK Climate Research Unit (Harris et al., 2014). A list of definitions for our explanatory variables is in Table A.1 in the Appendix.

Figure 2 gives an initial indication of the association between electricity consumption and subsequent economic growth. The line of best fit has a slight downward slope. It is possible, however, that the true relationship is obscured by other variables. As electricity consumption per capita is strongly correlated with GDP per capita, the weak negative relationship may merely reflect the cross-country convergence process in GDP per capita (Barro, 1991, 2015), for example. Our regression approach will control for this convergence process.

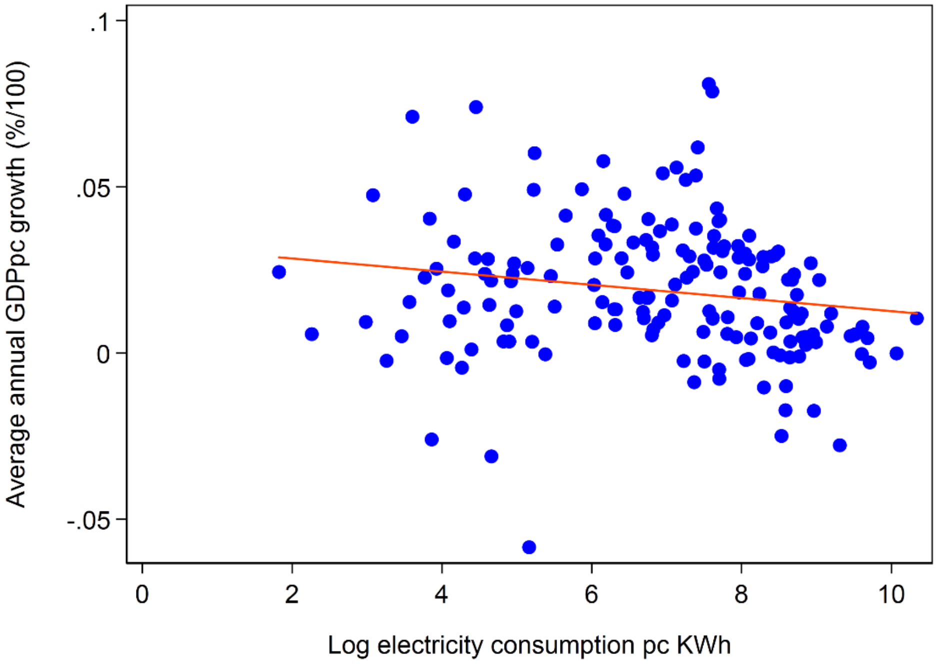

Figure 2. Log electricity consumption per capita (kilowatt hours per capita) in 2006 and average annual GDP per capita growth (difference of logged GDP per capita divided by 10) for the decade to 2016. All countries with available data are included; this is 170 countries. Sources: US EIA (2017), World Bank (2017b).

Sizeable differences in electricity consumption per capita between country groups are evident in Figure 3. High-income countries use well over 20 times more electricity than low-income countries on average.

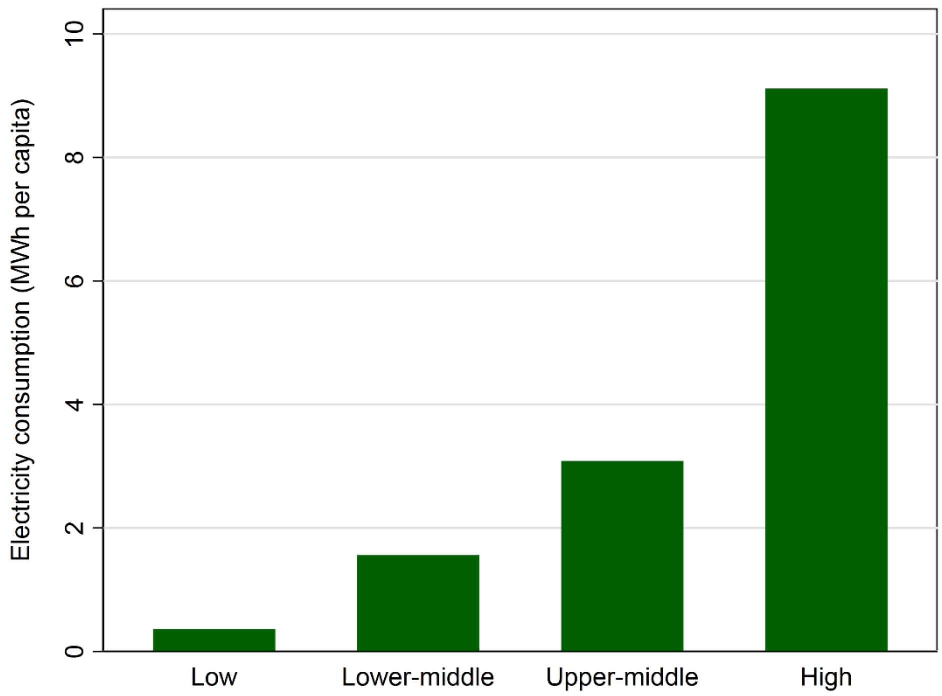

Figure 3. Electricity consumption per capita (megawatt hours), by income group, 2006. Sources: US EIA (2017), World Bank (2017b).

In an additional specification, equation (6) uses decadal changes rather than levels of the electricity explanatory variables. The electricity consumption and capacity variables are annualized changes for the prior decade (1996–2006), and the electricity losses variable is the difference between the 1996 and 2006 electricity loss values. The initial log GDP per capita term is included in the $\boldsymbol{x}$ vector in equation (6) and (7) to aid concise presentation.

$$(\ln Y_c^{2016} - \ln Y_c^{2006})/10 = \alpha + \varphi \Delta^{1996-2006} E_c + \gamma \boldsymbol{x}'^{2006}_c + \varepsilon_c \quad (6)$$

We also explore a panel approach. To maintain the focus on the decadal dependent variable and a reasonable sample size, we focus on a panel with two time periods: the decades to 2006 and 2016. The specification for this model, shown in equation 7, is similar to the previous equations, and also includes country (I_c) and time (I^t) fixed effects. Inclusion of country fixed effects controls for time-invariant sources of unobserved heterogeneity in decadal economic growth rates. The use of decadal growth rates and our focus on cross-sectional variation or variation over only two decades avoids issues of unit roots that might be present in studies using annual levels data (Chirinko, 2011; Stern et al. 2017b).

$$(\ln Y_c^{t} - \ln Y_c^{t-10})/10 = \alpha + \varphi \ln E_c^{t-10} + \gamma \boldsymbol{x}'^{t-10}_c + I_c + I^t + \varepsilon_c^t \quad (7)$$

One characteristic of our approach is that it will not pick up very long-run effects of electricity availability, for example effects that emerge from improved educational attainment among children. It will also not pick up same-year effects. Instead, we seek to detect whether electricity availability enhances economic growth during subsequent years within the decade.

Our approach seeks to address potential endogeneity issues in a number of ways. Using initial values for independent variables lessens the likelihood of reverse causation, a major risk given that electricity and economic growth follow very similar paths. Our lagged inputs do not preclude output being a function of current inputs or lags of a different length, although they do imply that we are only considering part of the relationship between electricity and output. It is also less likely that there would be reverse causation from a dependent variable measured as a growth rate than from a dependent variable measured as a level. To see this, consider that GDP per capita growth is less likely to cause educational attainment or life expectancy compared to the potential for the *level* of GDP per capita to influence these outcomes. Omitted variable bias could exist as there are many variables that are correlated with electricity that can contribute to economic growth and it may be difficult to control for all of them.

Instrumental variables are sometimes used to address endogeneity in studies using observational data, but there are major challenges to doing so in the current context. A potential instrument for electricity consumption could be electricity infrastructure, but electricity infrastructure may be built in anticipation of future demand and economic growth (Stern et al., 2017a). As an example of an instrument for electricity quality, Andersen and Dalgaard (2013) used lightning strikes as an instrument for power outages. Yet their instrument might be correlated with other variables that are relevant for economic growth, such as the incidence of conflict. Due to the difficulty of finding ideal instruments for our various electricity variables, we do not pursue an instrumental variable approach.

4. Results

The results in Table 2 control for only the initial level of log GDP per capita. We obtain a positive coefficient for the electricity consumption variable in column 1, significant at the one percent level. One percent more electricity consumption per capita in 2006 has on average been associated with 0.006 percentage points of additional economic growth per annum over the subsequent decade, holding the initial level of log GDP per capita constant. The industry-sector electricity variable in column 2 also has a positive coefficient, but is not statistically significant. The log of electricity capacity per capita and electricity access are also positive and significant at the one percent level in columns 3 and 5, respectively. The coefficient for electricity access suggests that a percentage point increase in electricity access is associated with 0.032 percentage points of additional economic growth per annum over the subsequent decade. Transmission and distribution losses show a negative coefficient in column 4, consistent with higher electricity losses representing greater inefficiency. The electricity quality coefficient is not significant.

The initial log GDP per capita variable in Table 2 has negative and significant coefficients, indicating convergence of economic output: countries with higher initial per capita GDP have slower subsequent growth in GDP per capita. The magnitudes of the coefficients for log GDP per capita in Table 2 are somewhat smaller (in absolute value terms) than the 1.7 percent annual convergence rate reported by Barro (2015).

We also explored if the results are sensitive to outliers. Results in Table 2 are similar if the countries with the fastest (China) and slowest (Yemen) economic growth for 2006–2016 are excluded.

Table 2. Results: electricity and GDP per capita growth to 2016

	Dependent variable: Average annual GDP per capita growth, 2006–2016					
	(1)	(2)	(3)	(4)	(5)	(6)
Log electricity consumption per capita	0.006***					
	(0.002)					
Log consumption of electricity by industry p.c.		0.004				
		(0.003)				
Log electricity capacity per capita			0.007***			
			(0.002)			
Electricity transmission and distribution losses				-0.033***		
				(0.011)		
Access to electricity					0.032***	
					(0.007)	
Electricity quality index						-0.002
						(0.002)
Log GDP per capita	-0.013***	-0.014***	-0.014***	-0.010***	-0.012***	-0.005*
	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)	(0.003)
Number of countries	170	126	170	129	176	115
R^2	0.152	0.272	0.188	0.261	0.179	0.207

Notes. ***, **, * show statistical significance at 1, 5 and 10 per cent level respectively. Robust standard errors are in brackets below the coefficients. Coefficients for constants are not shown. All explanatory variables are measured in 2006. The average annual rate of GDP per capita growth is calculated as the differenced logs divided by the number of years. Variable definitions and units are in Table 1 and Appendix Table A.1. The sample size varies due to data availability. Column (1) includes 41 high-income countries (as at 2006) and 129 developing countries (not high-income).

The estimates in Table 3 reveal that the results in Table 2 are sensitive to the inclusion of other controls, our main finding in this paper. The inclusion of the full set of controls renders most of the coefficients for the electricity variables statistically insignificant, with the exception of the negative coefficient for electricity transmission and distribution losses (although this variable does not maintain a significant coefficient in Table 4, below). The absence of significant effects suggests that electricity may not have major, readily-detectable effects on subsequent economic growth on average.

The coefficients for the controls in Table 3 are reasonable. Initial log GDP per capita again has negative and significant coefficients in three of the six columns. A positive impact of more open economies is evident. There are also significant negative coefficients for temperature, indicating that higher temperatures contribute to slower economic growth. This is comparable to other studies, but does not consider any non-linear effects of temperature. Burke et al. (2015) note that productivity peaks at 13 degrees Celsius and declines at higher temperatures. Results are similar when not controlling for regional binary variables.

The coefficients for log other energy per capita (excluding electricity) are negative and significant in two columns of Table 3, which may appear surprising, but can be explained. Given that initial log GDP per capita is also an explanatory variable, the other energy variable in our model is in effect testing whether initial energy intensity is relevant for future economic growth. The negative coefficients suggest that less energy-efficient economies performed more poorly in terms of their subsequent economic growth in the decade to 2016. Poor performance in energy efficiency may be due to distortions such as energy subsidies. As a result, resource allocation may be less efficient in these economies. It is also possible that use of high-quality energy forms such as electricity is more beneficial than use of lower-quality energy forms. When combining the other energy variable (excluding electricity) with electricity in a log total energy use variable (including electricity), the coefficient is not negative in explaining subsequent GDP per capita growth (see Stata files in the Supplementary material section).

Table 3. Results: electricity and GDP per capita growth to 2016, with controls

	Dependent variable: Average annual GDP per capita growth, 2006–2016					
	(1)	(2)	(3)	(4)	(5)	(6)
Log electricity consumption per capita	0.004					
	(0.003)					
Log consumption of electricity by industry p.c.		0.004				
		(0.003)				
Log electricity capacity per capita			0.004			
			(0.003)			
Electricity transmission and distribution losses				-0.026**		
				(0.010)		
Access to electricity					0.007	
					(0.012)	
Electricity quality index						-0.002
						(0.002)
Log GDP per capita	-0.010**	-0.002	-0.010**	-0.002	-0.010**	-0.001
	(0.004)	(0.005)	(0.004)	(0.004)	(0.005)	(0.005)
Log other energy per capita	-0.001	-0.010***	-0.000	-0.008**	0.001	-0.006
	(0.003)	(0.004)	(0.003)	(0.004)	(0.003)	(0.004)
Inflation, consumer prices	-0.001*	-0.001	-0.001*	-0.001	-0.001	-0.001**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log life expectancy	0.055**	0.041	0.050*	0.045	0.052*	0.008
	(0.026)	(0.038)	(0.026)	(0.040)	(0.029)	(0.035)
Education index	0.007	0.027	0.008	0.032	0.014	0.020
	(0.024)	(0.023)	(0.024)	(0.024)	(0.025)	(0.024)
Trade openness	0.006**	0.005*	0.006**	0.005*	0.006**	0.006**
	(0.003)	(0.003)	(0.002)	(0.003)	(0.002)	(0.003)
Temperature	-0.010***	-0.006*	-0.010***	-0.008**	-0.010***	-0.007*
	(0.003)	(0.004)	(0.003)	(0.004)	(0.003)	(0.004)
Number of countries	140	118	140	121	140	104
R^2	0.400	0.467	0.399	0.462	0.389	0.515

Notes. ***, **, * show statistical significance at 1, 5 and 10 per cent level respectively. Robust standard errors are in brackets below coefficients. Coefficients for constants, governance variables (political stability, control of corruption, and government effectiveness), and regional binary variables are not shown. Results are similar if the regional binary variables and control of corruption variable are excluded. All explanatory variables are measured in 2006. The sample size varies due to data availability.

We also address the potential for multicollinearity in the results as there are many explanatory variables that could be highly correlated. For instance, the correlation between log other energy use (total energy minus the energy in electricity) and log electricity consumption is 0.87. Despite this high correlation, the variance inflation factor for these variables is below a commonly used threshold of 10, suggesting that multicollinearity may not be having a major effect on raising the coefficient standard errors. We also find similar results when excluding log other energy as a control (see Stata files in the Supplementary material section). In particular, the electricity coefficient magnitudes remain similar, and 4 out of 6 end up as insignificant, compared to 5 out of 6 when other energy is included as a control.

We also produce results with subsets of the data to test if results differ for various groups. For instance, we find similar results (see Stata files in the Supplementary material section) if countries in the Organization of the Petroleum Exporting Countries (OPEC) are excluded, suggesting that the non-significant results for most electricity variables are not driven by countries with an economic focus on oil production.

Table 4 uses prior-decade changes in electricity rather than initial electricity levels as independent variables for a developing country sample that excludes high-income countries. The potential for differing impacts of energy on economic outcomes for individual countries at different stages of development has been investigated in some previous studies (Fatai et al., 2004, for example). There are some positive coefficients for the change in electricity consumption and capacity variables in the first three columns, including significance at the five percent level for per capita electricity used by the industrial sector.

The final four columns of Table 4 include GDP per capita growth from the prior decade (1996–2006) as a control. The electricity coefficients mostly become smaller, and the significance of the electricity use by industry variable disappears.

The change in GDP per capita from the prior decade (1996–2006) has positive and significant coefficients in two columns in Table 4. This implies that countries that experienced faster economic growth in the decade 1996–2006 also experienced faster economic growth in the decade 2006–2016 when controlling for other variables. Whilst economic growth has been described as lacking persistence and having low predictive power for future economic growth (Easterly et al., 1993; Rodrik 1999; Pritchett 2000), it is not uncommon for growth trends to continue for one or more decades.

Table 4. Results: change in electricity (1996–2006) and GDP per capita growth (2006–2016), excluding high-income countries

	Dependent variable: Average annual GDP per capita growth, 2006–2016							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Growth rate, electricity consumption per capita (1996–2006)	0.066				0.028			
	(0.040)				(0.048)			
Growth rate, electricity cons. by industry p.c. (1996–2006)		0.051**				0.008		
		(0.022)				(0.022)		
Growth rate, electricity capacity per capita (1996–2006)			0.034				0.003	
			(0.060)				(0.059)	
Change, electricity transmission & dist. losses (1996–2006)				-0.007				0.010
				(0.014)				(0.014)
Growth rate, GDP per capita (1996–2006)					0.103	0.343***	0.119	0.342***
					(0.113)	(0.091)	(0.099)	(0.093)
Log GDP per capita	-0.010**	0.003	-0.011**	-0.003	-0.013**	0.001	-0.013**	-0.006
	(0.005)	(0.006)	(0.005)	(0.007)	(0.005)	(0.005)	(0.005)	(0.007)
Log other energy per capita	0.001	-0.015**	0.002	-0.011*	0.002	-0.012**	0.002	-0.007
	(0.004)	(0.006)	(0.004)	(0.006)	(0.004)	(0.005)	(0.004)	(0.006)
Inflation, consumer prices	-0.000	0.000	-0.000	-0.000	0.000	0.003***	0.000	0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log life expectancy	0.027	0.014	0.028	0.017	0.030*	0.017	0.032*	0.016
	(0.017)	(0.020)	(0.018)	(0.019)	(0.018)	(0.016)	(0.019)	(0.016)
Education index	0.025	0.015	0.018	0.038	0.026	0.004	0.023	0.036
	(0.029)	(0.029)	(0.031)	(0.041)	(0.029)	(0.026)	(0.031)	(0.039)
Trade openness	-0.001	-0.001	-0.002	-0.004	-0.002	-0.002	-0.002	-0.006
	(0.006)	(0.007)	(0.006)	(0.008)	(0.006)	(0.005)	(0.006)	(0.007)
Temperature	-0.005	-0.006*	-0.005	-0.004	-0.003	-0.000	-0.003	0.002
	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.003)	(0.004)	(0.004)
Number of countries	100	78	100	82	99	78	99	82
R^2	0.218	0.252	0.207	0.190	0.236	0.414	0.234	0.321

Notes. ***, **, * show statistical significance at 1, 5 and 10 per cent level respectively. Robust standard errors are in brackets below the coefficients. Coefficients for constants and governance variables (political stability, control of corruption, and government effectiveness) are not shown. Electricity variables are the change from 1996–2006: consumption and capacity are average annual growth rates, while losses is the 10-year difference. All control variables are measured in 2006, except the change in GDP per capita is from 1996–2006. The sample size varies due to data availability.

Table 5 shows similar results using log electricity capacity per capita with a panel approach covering two time periods: the decades to 2006 and 2016. When the only control is the log of GDP per capita at the start of the decade of growth, there is a positive coefficient for the log of electricity capacity at the start of the decade of 0.011 in column 1, significant at the one percent level. Including regional binary variables reduces the electricity coefficient to 0.008 in the second column. The following three columns successively add more controls. Column 3 adds log other energy use, inflation, trade openness, and temperature, resulting in an electricity coefficient of 0.005, approximately half the magnitude in column 1. Adding governance variables in column 4 does not have a major impact on the electricity coefficient magnitude. We do not find significant effects of the governance variables on subsequent economic growth. Interestingly, however, we find that countries that have achieved better health outcomes experience faster economic growth in the subsequent decade, holding the values of the other variables constant. There is still a positive and significant coefficient for log electricity capacity in column 5 when controlling for an initial education index and log life expectancy.

The final column of Table 5 includes country and time fixed effects. An insignificant coefficient is obtained for the log of electricity capacity. This is further evidence that the significance of electricity tends to disappear in growth regressions as controls are added. Our finding is thus similar in nature to Acemoglu et al. (2008)'s finding on the effect of income on democracy; they also found that adding controls – including fixed effects – removes evidence of a significant effect. Barro (2015) explains that including country fixed effects can inflate the coefficient on the convergence term, which is indeed what we find in our column 6 estimate.

Other electricity variables with a long time-series, such as electricity consumption or electricity used by the industrial sector, also produce the pattern of reducing coefficients and disappearing significance when adding more controls. The electricity coefficients are also similar when restricting the sample to exclude high-income countries. We also obtain similar results (see Stata files in the Supplementary material section) to Table 5 using four 5-year periods to 2016 rather than two decades to 2016.

Table 5. Panel results: electricity capacity per capita and decadal GDP per capita growth, 1996–2016.

	Dependent variable: Average annual GDP per capita growth for decades to 2006 and 2016					
	(1)	(2)	(3)	(4)	(5)	(6)
Log electricity capacity per capita	0.011***	0.008***	0.005**	0.006**	0.006*	0.003
	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.006)
Log GDP per capita	-0.019***	-0.018***	-0.021***	-0.020***	-0.021***	-0.077***
	(0.003)	(0.002)	(0.004)	(0.004)	(0.004)	(0.007)
Log other energy per capita			0.008***	0.007**	0.009***	-0.015
			(0.003)	(0.003)	(0.003)	(0.010)
Inflation, consumer prices			0.000	0.000	-0.000	0.001
			(0.000)	(0.000)	(0.003)	(0.001)
Trade openness			0.003	0.003	0.003*	0.006
			(0.002)	(0.002)	(0.002)	(0.006)
Temperature			-0.005*	-0.006*	-0.007**	-0.061***
			(0.003)	(0.003)	(0.003)	(0.017)
Political stability				0.000	-0.001	-0.004
				(0.002)	(0.002)	(0.003)
Control of corruption				-0.002	-0.000	-0.007
				(0.005)	(0.005)	(0.005)
Government effectiveness				0.000	-0.002	0.004
				(0.005)	(0.005)	(0.006)
Log life expectancy					0.062**	0.134***
					(0.025)	(0.045)
Education index					-0.034**	0.041
					(0.016)	(0.041)
Number of observations	343	343	262	262	252	252
Regional binary variables	No	Yes	Yes	Yes	Yes	No
Fixed effects (country and time)	No	No	No	No	No	Yes
R^2 (within)						0.636

Notes. ***, **, * show statistical significance at 1, 5 and 10 per cent level respectively. Robust standard errors are in brackets below coefficients. Coefficients for constants and regional binary variables are not shown. All explanatory variables are measured at the start of the decadal growth period. The sample size varies due to data availability.

There are a number of potential explanations for our finding of insufficient evidence that electricity affects economic growth, when including other economic growth determinants in Table 3, prior economic growth in Table 4, and fixed effects (country and time) in Table 5. The electricity coefficients could be non-significant due to the absence of an average effect; due to model specification error; or due to inadequate sample size to detect the true effect. We do not accept the null hypothesis that electricity has no effect on economic growth, but instead conclude that the results are consistent with electricity availability not on its own tending to be a detectably vital pre-determinant of subsequent economic growth.

5. Conclusion

The main finding of this paper is that electricity availability does appear to be important for economic growth when other potential explanators are ignored, but that the significance of this effect mostly disappears when controlling for key growth determinants. We obtain this result using decadal regressions that focus on the medium-run impact of electricity on subsequent economic growth. It is possible that there are larger effects over a longer time window than ten years. Other studies have also identified growth determinants that have significant coefficients that disappear upon further testing, for example public debt (Panizza and Presbitero, 2014).

Our estimates provide evidence of important non-electricity determinants of economic growth, including economic and geographic variables. We find that the convergence of GDP per capita levels occurs at the rate of approximately one to two percent per year. We also find a positive effect from trade openness to economic growth and a negative association with temperature.

It is important to note that our results do not imply that electricity is dispensable for modern economies. All high-income economies have near universal electrification rates. The success of rapidly-developing economies such as China and Vietnam has involved substantial increases in electricity use (Stern et al., 2017a). Electricity is vital for many economic activities, and is likely to become an even more important source of energy as transport and other energy uses continue to electrify in the years ahead. Our results instead imply that, looking across countries and holding other key variables constant, there is no strong difference in the subsequent economic growth performance of countries with varying levels of initial electricity availability.

Our findings provide important background information for policymakers considering expansion of electricity availability. They suggest that expectations of sustained increases in economic growth rates as a result of electrification programs alone may not be justified. This is consistent with micro-level evidence that electrification does not always result in large-scale transformations of local economies (Lee et al., 2016). Our results are consistent with the idea that, instead of being a clearly-detectable "binding constraint" (Hausmann et al., 2008) to economic growth, electricity availability is something that is able to be scaled up as countries grow. This is a specific example of the co-evolution of public infrastructure and per-capita GDP discussed by Daido and Tabata (2013). Distributed electricity technologies are increasing the extent to which electricity availability can be rapidly scaled up.

Even if electrification programs do not have detectable direct benefits for subsequent economic growth, there are broader social, health, and sometimes environmental benefits from having access to electricity. These could justify expansion of electricity availability in their own right. It is also possible that there are direct effects of specific energy types on economic output. For instance, renewable energy consumption has been found to have a positive impact on economic output in some countries (Bhattacharya et al., 2016).

Future research could further consider the empirical relationship between electricity availability and social and environmental outcomes, at both the micro and macro levels. There is also scope for examining whether the economic effects of electrification differ depending on whether electrification relies on distributed technologies or on extension of the electricity grid. Our approach of separately considering multiple aspects of electricity availability is a useful framework for future studies.

Appendix

Table A.1 Definitions for non-electricity variables

Variable	Source	Description
GDP per capita growth	WDI	Differenced logs of GDP per capita divided by the length of time.
Log GDP per capita	WDI	Log of GDP per capita in purchasing power parity constant 2011 international dollars.
Log other energy per capita	WDI, EIA	Energy use per capita from WDI minus electricity consumption per capita from EIA (both in kilograms of oil equivalent), log.
Inflation, consumer prices	WDI	Inflation, consumer prices, annual (% / 100).
Trade openness	WDI	Exports plus imports of goods and services, percentage of GDP, divided by 100.
Temperature	CRU	Temperature, degrees Celsius, divided by 10. Climate dataset CRU CY v.3.22.
Political stability	WGI	An index relating to the lack of violence in addition to stability more generally. The index values are normally distributed with mean zero and standard deviation of one.
Control of corruption	WGI	An index representing the extent to which public power being used for private gain is avoided.
Government effectiveness	WGI	An index representing quality of public services and of policy formulation and implementation.
Log life expectancy	WDI	Log of life expectancy at birth, total, in years.
Education	UNDP	Education index from Human Development Index data, values range from 0 to 1.

Notes. Sources: CRU: Climate Research Unit (UK): Harris et al. (2014), EIA: US Energy Information Administration (2017), UNDP: United Nations Development Programme (2016), WDI: World Bank (2017b) World Development Indicators, WGI: Worldwide Governance Indicators (2016).

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