



The effect of renewable and nonrenewable electricity generation on economic growth

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ABSTRACT

This note examines the impact of electricity generation on economic growth using data for a panel of 174 countries over the period 1980–2012. The paper makes several contributions. First, contrary to much of the literature, the paper focuses on the effect of *electricity generation* on economic growth. Because of transmission and distribution losses, and theft, not all the electricity that is generated is eventually consumed, making it necessary to investigate the impact of electricity generation on growth. Second, we disentangle the impact of total electricity generation on growth into renewable and nonrenewable effects. With increasing pursuit of energy security, technological advances, the falling costs of renewables, and the movement to exploit renewable energy sources for electrification, there is need to study not only the impact of traditional sources of electricity but renewable sources, as well. Third, we deviate from previous studies that focus on granger causality and/or cointegration by estimating the effect of electricity generation on growth using the System Generalized Method of Moments (GMM). Given that electricity generation and many of the other regressors in our model may be jointly determined with GDP growth, the System GMM approach is appropriate to deal with these endogeneity issues. Fourth, we provide evidence of a link between electricity loss and economic growth. Our results indicate a strong positive and statistically significant relationship between renewable and nonrenewable electricity generation, and growth.

1. Introduction

Many things have changed to shape the world we live in today. Underlying them all is an abundant, relatively uninterrupted supply of energy. Energy is fundamental to all sectors of modern economies, and therefore underpins all of our economic activities. Yet if current trends continue, global energy demand is projected to double by 2050.¹ How then can we increase global energy supply to satisfy this growing demand? How can we develop reliable, alternative, and sustainable energy sources to meet that demand? What will be the environmental, political, and economic consequences of this increase in energy demand?

Extensive research in economics and related disciplines has sought to address these questions. One aspect of energy that has received considerable attention recently is the impact of electricity on economic growth. Much of the existing literature has focused on granger causality between the two variables, resulting in mixed findings due to different samples, empirical methodologies, or both. Using annual U.S. data from 1947 to 1974, Kraft and Kraft (1978) find unidirectional causality

running from GNP to energy consumption. Acaravci and Ozturk (2010) find no evidence of cointegration between electricity consumption and gross domestic product (GDP) per capita in a panel study of 15 transition countries. Employing panel vector error correction models, Apergis and Payne (2011a) report bidirectional causality between electricity consumption and economic growth in both the short- and long-run for high and upper middle income countries, but find bidirectional causality for lower-middle income countries only in the long-run. For low income countries, they document a unidirectional causality running from electricity consumption to economic growth.

With growing concerns about climate change, and the constant development of alternative sources of electricity, recent papers have argued that examining the relationship between total electricity consumption and economic growth may be misleading as the response of economic growth may differ depending on whether the source of electricity is renewable versus nonrenewable. As a consequence, the use of more disaggregate data when examining the impacts of electricity consumption on economic growth has recently received some attention. Al-mulali et al. (2014) look at renewable and nonrenewable electricity

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¹ https://www.worldenergy.org/wp-content/uploads/2012/10/scenarios_study_es_online.pdf.

consumption for 18 Latin American countries, finding that they each had a positive impact on growth in the short and long run. They also find a larger estimate of the impact of renewable electricity consumption than that of nonrenewable electricity consumption. Pao and Fu (2013) find a bidirectional relationship between economic growth and total renewable energy consumption for Brazil, while Apergis and Payne (2012) and Apergis and Danuletiu (2014), using data for 80 countries over the period 1980–2012, report bidirectional causality between renewable electricity consumption and nonrenewable electricity consumption, and economic growth. Varying conclusions on the direction of causality between renewable and nonrenewable electricity consumption and economic growth has also been documented in several recent papers, including Apergis and Payne (2010, 2011b), and Halkos and Tzeremes (2014). This vast empirical literature, coupled with contrasting findings on the relationship between (renewable and nonrenewable) electricity consumption and economic growth clearly indicates that this topic remains of interest to economists.

The purpose of this paper is to investigate the impact of renewable and nonrenewable *electricity generation* on economic growth using data for a panel of 174 countries over the period 1980–2012. The paper makes several contributions to the literature. First, while previous papers have focused on the impact of electricity *consumption* on economic growth, this paper focuses on the effect of electricity *generation* on growth. Because of transmission and distribution losses, as well as theft, not all of the electricity that is generated in a country is eventually consumed. In fact, Depuru et al. (2011) report that global transmission and distribution electricity losses are estimated to exceed the total generation capacity of the United Kingdom, Germany, and France, which translates to a loss of more than \$25 billion annually. These losses due to transmission, distribution, and theft, coupled with the fact that some electricity that is generated is exported rather than consumed, imply that the impact of electricity *generation* on economic growth may differ from that of electricity *consumption*. Second, and perhaps the most important contribution of the paper, is that we deviate from previous studies that employ granger causality and/or cointegration approaches by estimating the effect of electricity generation on growth using the System GMM estimator (Arellano and Bover, 1995; Blundell and Bond, 1998). Given that electricity generation and many of the other regressors in our model may be jointly determined with GDP growth, the System GMM approach is appropriate to deal with these endogeneity issues. An added advantage of the System GMM estimator, pointed out by Bond (2002) is that if the data are susceptible to measurement error, longer lags of the regressors can be used as instruments to alleviate this problem. We test the validity of the orthogonality assumptions underlying the system GMM estimator using the Hansen test of overidentification and the Arellano and Bond (1991) test of second-order serial correlation, and employ the Windmeijer (2005) small sample correction of the standard errors in all two-step System GMM estimations. Third, we shed further light on the impacts of electricity generation by disaggregating total electricity generation into separate measures of renewable and nonrenewable electricity generation. Fourth, we provide empirical evidence that electricity losses during transmission, distribution, or due to theft are detrimental for economic growth. Fifth, in addition to controlling for the effects of education, trade, government consumption, and other economic and social factors that directly affect growth, our panel estimation strategy also includes country-fixed effects to control for the possibility that there are important unobservable variables inducing omitted variables bias. Year effects are also included to control for year-to-year variations in economic growth rates that are common across countries.

Our results indicate a strong positive and statistically significant relationship between electricity generation and growth. When we disaggregate total electricity generation into renewable and nonrenewable generation, the results remain positive and significant. A battery of tests show that these findings are robust across different measures of electricity generation, and different model specifications. Our results also

indicate that electric power losses resulting from transmission, distribution, and theft have a statistically significant negative relationship with economic growth. With increasing awareness of clean energy sources and rising concern about climate change, the finding that renewable and nonrenewable electricity generation each have positive impacts on economic growth implies that countries can gradually transition to renewable or (cleaner) nonrenewable sources without necessarily impeding economic growth. The remainder of the paper is as follows. Section 2 presents the data and methodology, Section 3 discusses the empirical results, and Section 4 concludes.

2. Data and methodology

Our dataset consists of annual data for a panel of 174 countries over the period 1980–2012. The dependent variable in our model is the growth rate of real GDP per capita. Data on GDP per capita for each country, and the ensuing growth rate were collected from the Economic Research Service of the U.S. Department of Agriculture (USDA). Our main explanatory variable of interest is (renewable and nonrenewable) net electricity generation (billion Kilowatt hours). The data for total renewable and nonrenewable electricity net generation are from the U.S. Energy Information Administration (EIA). Net electricity generation excludes the energy used by the generating units. Renewable electricity generation includes hydroelectricity, geothermal, wind, solar, tidal, wave, fuel cell, biomass and waste, while nonrenewable electricity generation includes fossil fuel derived sources including coal, natural gas, and oil. In a robustness section, we use an alternative dataset on renewable and nonrenewable electricity generation as a percentage of total electricity production. The data comes from the World Bank, and only covers the period 1990–2012.

We draw liberally from the empirical and theoretical growth literature on the choice of the other explanatory variables that affect per capita GDP growth. Following Barro (1996), we include the initial level of GDP per capita, gross primary school enrollment rate, life expectancy, foreign direct investment, net official development assistance and official aid received, the inflation rate, trade, government final consumption expenditure, savings rate, and fertility rate as control variables. Data for the above mentioned variables were collected from the World Bank. Following the literature, the initial level of (the log) GDP per capita is included to account for conditional convergence across countries. Consistent with the predictions of the neoclassical growth model, the coefficient on this variable is expected to be negative. We include life expectancy to proxy for health status, while gross primary school enrollment is included to proxy for the effects of human capital on growth. While the theoretical literature generally finds a positive effect of human capital on growth, empirical findings have produced conflicting results.² Our model also controls for the ratio of government final consumption expenditure to GDP (net of education and defense spending) to approximate the effects of nonproductive government spending (Barro, 1996), and is expected to be growth-retarding. Because inflation is not only costly but also creates uncertainty, businesses and households generally perform poorly when inflation is high and unpredictable, so it is expected to have negative growth effects (Briault, 1995). Becker and Barro (1988) argue that higher fertility rate decreases growth because it causes resources to be diverted to child-bearing, rather than to the production of goods and services. We also control for the effect of foreign direct investment and net official development assistance and official aid received. The evidence on the effect of net official development assistance and official aid received on economic growth is mixed. Several researchers contend that a large portion of net official development assistance and official aid to

² E.g. Barro (1996) finds negative and insignificant effects of male and female primary enrollment on subsequent economic growth, but positive and significant impacts of upper-level schooling on long-run growth.

Table 1
Variable definitions, data sources, and summary statistics.

Variable	Definition	Mean	SD
GDP per capita (USDA)	Natural logarithm of gross domestic product divided by midyear population	8.1617	1.5770
Growth (USDA)	GDP per capita growth rate	1.6131	6.6669
Total Electricity (EIA)	Growth of total electricity generation from all sources (thousand Megawatthours)	3.3735	10.9105
Renewable (EIA)	Growth of electricity generation from renewable a sources (thousand Megawatthours)	3.8125	23.3642
Nonrenewable (EIA)	Growth of electricity generation from nonrenewable a sources (thousand Megawatthours)	4.0001	21.7917
Renewable (World Bank)	Share of electrity generated by renewable power plants in total electricity generated by all plants	0.9694	26.1045
Nonrenewable (World Bank)	Share of electrity generated by nonrenewable power plants in total electricity generated by all plants	−0.5781	35.4523
Electricity Loss (World Bank)	Losses in transmission between sources of supply and points of distribution and in the distribution to consumers, including pilferage	2.4053	0.6783
Primary enrollment (World Bank)	Total enrollment in primary education, as a percentage of population of primary education age	97.9778	20.6518
Life expectancy (World Bank)	Number of years a newborn infant would live if patterns of mortality at the time of its birth were to stay the same throughout its life	68.4226	10.9302
Foreign aid (World Bank)	Natural log of net official development assistance and foreign aid received as a percentage of GDP	18.7734	1.6512
Trade (World Bank)	Percentage ratio of export unit value indexes to import unit value indexes, relative to base year 2000	112.402	41.2626
Inflation rate (World Bank)	Annual growth rate of the GDP implicit deflator	0.4828	5.5614
Government (World Bank)	Government expenditures for purchases of goods and services as a percentage of GDP	0.1635	0.0682
Fertility rate (World Bank)	Natural logarithm of number of children born to a woman during her childbearing years and in accordance with age-specific fertility rates of the specified year	1.1395	0.5491
FDI (World Bank)	Foreign direct investment: net inflows of foreign investment as a percentage of GDP	3.8856	13.6188
Savings rate (World Bank)	Gross national income less total consumption, plus net transfers as a percentage of GDP	0.1996	0.13056

developing countries is wasted, and only leads to unproductive public consumption due to poor institutions, high levels of corruption and bureaucratic failures in less developed countries (Alesina and Dollar, 2000; Dollar and Pritchett, 1998). However, in the last several years, many studies using panel data have repeatedly found evidence that net official development assistance and official aid received has a positive impact on growth. Because the controversy on the effect of net official development assistance and official aid received on growth is not whether it affects growth, but the direction of the effect, it is necessary to control for it in our model. Following the Solow growth model, the savings rate is included as it determines a country's steady-state level of income per capita. Furthermore, because the savings rate is correlated with some of the other regressors, its omission will cause an omitted variables bias problem.

The baseline model to estimate the impact of electricity generation on growth is:

$$growth_{it} = \beta_1 + \beta_2 y_{i,t-1} + \beta_3 Electricity_{it} + X'_{it} \gamma + \delta_t + \varphi_i + \varepsilon_{it} \quad (1)$$

In Eq. (1), the left hand side variable is the growth rate of per capita GDP for country i in period t . On the right hand side, $y_{i,t-1}$ denotes the natural log of per capita GDP of country i in period $t-1$; $Electricity_{it}$ represents the growth of electricity generation of country i in period t ; X is the vector of controls for country i in year t that includes gross primary school enrollment rate, life expectancy, foreign direct investment, net official development assistance and official aid received, trade, inflation, government consumption, fertility rate, and the savings rate. δ_t denotes unobservable time effects; φ_i , time-invariant country effects; and ε_{it} is the error term. Table 1 provides descriptive statistics, variable definitions, and data sources.

Eq. (1) is generally not estimated by Ordinary Least Squares (OLS), fixed effects, or random effects panel data methods because it contains a lagged endogenous variable, $y_{i,t-1}$. This is more clearly apparent if GDP per capita growth ($growth_{it}$) is rewritten so that Eq. (1) becomes:

$$y_{it} - y_{i,t-1} = \beta_1 + \beta_2 y_{i,t-1} + \beta_3 Electricity_{it} + X'_{it} \gamma + \delta_t + \varphi_i + \varepsilon_{it} \quad (2)$$

Adding $y_{i,t-1}$ to both sides of Eq. (2) and rearranging gives:

$$y_{it} = \beta_1 + (\beta_2 + 1)y_{i,t-1} + \beta_3 Electricity_{it} + X'_{it} \gamma + \delta_t + \varphi_i + \varepsilon_{it} \quad (3)$$

which can be again rewritten as:

$$y_{it} = \beta_1 + \delta_2 y_{i,t-1} + \beta_3 Electricity_{it} + X'_{it} \gamma + \delta_t + \varphi_i + \varepsilon_{it} \quad (4)$$

where $\delta_2 = \beta_2 + 1$. The presence of this lagged dependent variable causes y_{it} to be correlated with φ_i , causing OLS to be upward biased and

inconsistent (Hsiao, 1986). To see this more clearly, assume that for some reason a country experiences a large negative macroeconomic shock that causes a decrease in GDP per capita growth (the dependent variable) in a given period, however, the effect of the shock is not explicitly modeled in Eq. (4) but is rather captured in the error term. This negative shock in one year will cause the average fixed effect for that country over the entire sample period to be lower. In the following year, lagged GDP per capita (a regressor) and the fixed effect will both be lower. The positive correlation between lagged GDP per capita and the error term renders OLS estimation biased and inconsistent because it violates the OLS assumption that the error term is independent of the regressors. In fact, this positive correlation increases the estimate of the coefficient on lagged GDP per capita because it assigns explanatory power to it rather than to the country's fixed effect. Worse still, fixed effects estimation of Eq. (4) does not eliminate the bias as the coefficient on lagged GDP per capita is downward biased. To see this, consider what happens under fixed effects estimation of Eq. (4). The within transformation of lagged GDP per capita becomes $y_{i,t-1}^* = y_{i,t-1} - \frac{1}{T-1}(y_{i2} + \dots + y_{iT})$ and that of the error term is $\varepsilon_{it}^* = \varepsilon_{it} - \frac{1}{T-1}(\varepsilon_{i2} + \dots + \varepsilon_{iT})$.³ The negative bias of fixed effects estimation results because $y_{i,t-1}$ in $y_{i,t-1}^*$ has a negative correlation with $-\frac{1}{T-1}\varepsilon_{i,t-1}$ in ε_{it}^* , while $-\frac{1}{T-1}y_{it}$ and ε_{it} are also correlated. This problem is further compounded by the fact that lagged values of $y_{i,t-1}$ cannot be used as instrumental variables for $y_{i,t-1}^*$ as they too are embedded in ε_{it}^* .

To sidestep these problems, many dynamic panel studies use the Arellano and Bond GMM estimator which uses internal instruments to deal with the correlation between $y_{i,t-1}$ and φ_i . Arellano and Bond (1991) show that for short dynamic panels, Eq. (1) is first-differenced to remove φ_i . A more consistent estimator can be obtained by using lagged values of the levels of the right-hand side variables as predetermined instruments (Arellano and Bond, 1991). In particular, if φ_i ($i = 1, 2, \dots, N$) are serially uncorrelated, the second- and higher-order lags of the right-hand side are valid instruments. One drawback of the Arellano and Bond (1991) estimator, pointed out by Arellano and Bover (1995), and Blundell and Bond (1998) is that if the regressors display persistence over time, using lags of the regressors in levels may be poor instruments for the regressors in first differences. Arellano and Bover (1995), and Blundell and Bond (1998) advocate for the use of the System GMM which estimates two sets of equations - one set in levels that uses lags of the regressors in first-

³ The use of the lagged endogenous variable causes the sample to begin in period to be $t = 2, \dots, T$.

differences as instruments, and another set in first differences that uses lags of the regressors in levels as instruments. [Blundell and Bond \(2000\)](#) show that the System estimator performs better than the difference estimator in reducing endogeneity bias.

Besides dealing with endogeneity problems inherent in the data, the System GMM estimator has two further advantages. First, if the data suffer from measurement error, as it is often the case with cross-country data, [Bond \(2002\)](#) points out that using suitably longer lags of the regressors as instruments significantly reduces time-varying measurement error bias, while the country fixed effects absorb time-invariant measurement error ([Brühlhart and Mathys, 2008](#)). Second, when the data display a high degree of persistence, the Arellano and Bond difference GMM estimator suffers from weak instrument bias. [Blundell and Bond \(2000\)](#) provide additional moment conditions under which Eq. (1) can be estimated consistently using the System GMM estimator.

In this paper, we use the System estimator to deal with the endogeneity introduced by the inclusion of y_{it-1} , the potential endogeneity of the other explanatory variables, given that electricity generation and many of the other regressors may be jointly determined with GDP growth, and potential measurement errors resulting from the use of cross country data that display high persistence. Given the System GMM estimator's reliance on "internal" instruments, it is crucial to test the validity of the orthogonality assumptions underlying the System GMM estimator. We test these assumptions using the Hansen test of overidentification and the Arellano and Bond test for second-order and higher-order serial correlation (AR(2) test). We employ the [Windmeijer \(2005\)](#) small sample correction of the standard errors in all two-step System estimations.

3. Results and discussion

We first examine the impact of total electricity generation on economic growth in [Section 3.1](#), while results for the effects of renewable and nonrenewable electricity generation are discussed in [Section 3.2](#). [Section 3.2](#) also presents some empirical evidence on the impact of electricity loss on economic growth.

3.1. Effect of total electricity generation

[Table 2](#) presents the estimation results for the impact of total electricity generation on growth. For comparison, columns 1 and 2 of [Table 2](#) respectively report the OLS and fixed effects estimation results of Eq. (1), while column 3 presents the baseline System GMM estimates. Columns 4 and 5 report alternative System estimates for robustness purposes.

As discussed earlier, OLS estimation of Eq. (1) causes the estimate of lagged per capita GDP to be upward biased, while the fixed effects estimate is downward biased. As pointed out by [Bond et al. \(2001\)](#), a consistent estimate should lie between the OLS and fixed effects estimates. Looking at column 3, the two-step System GMM estimate of the coefficient on lagged per capita GDP of -1.538 lies in the credible range between the upward-biased OLS estimate of -1.020 and the downward-biased fixed effects estimate of -5.319 . Furthermore, the coefficient is negative and highly statistically significant, providing strong evidence in support of conditional convergence across countries. Cross-country evidence of conditional convergence has been documented by [Sala-i-Martin \(1997\)](#); [Barro and Sala-i-Martin \(1991, 1992\)](#), and [Badunenko and Romero-Ávila \(2013\)](#).

The two-step System GMM estimate of the coefficient on our main variable of interest - *Electricity_{it}* - is 0.101 and highly significant (standard error = 0.027) at any conventional level of significance, indicating that electricity generation enhances economic growth. Without reporting tests of overidentifying restrictions, as well as a test for second-order or higher-order serial correlation, it is difficult to evaluate this finding, or assign much credibility to it. The p - value of the AR(2) test is 0.012 , indicating that there is no significant evidence of second- or higher-

order serial correlation in the residuals in differences, while the Hansen test for overidentification shows no evidence against the validity of the instruments.

The coefficients on the other control variables are generally consistent with theory and/or previous empirical findings. The coefficient on primary school enrollment is negative but statistically insignificant. While this finding may seem surprising, many empirical papers have in fact documented negative and insignificant effects of primary school enrollment on economic growth. For example, using panel data for 113 countries over the period 1965–1995, [Barro \(2003\)](#) finds that male upper-level (secondary and higher schooling) education has a positive and significant effect on growth, but female upper-level schooling and lower-level (primary) schooling for both sexes have negative and insignificant coefficients. [Pritchett \(2001\)](#) also finds negative coefficients for the education variables included in his work and points to the possibility that educational capital in some countries may be directed into unproductive activities. While data on female and male upper-level schooling are available for most countries in our sample, they are mostly only available at 5- or 10-year intervals, thereby constraining us to use primary enrollment as our measure of educational attainment. In addition, much of the available cross-country educational attainment data, including the one used in this paper, measure years of schooling or enrollment rates and do not adjust for cross-country differences in school quality. Therefore, our finding of an insignificant effect of primary school enrollment is in fact in accordance with previous empirical work.

Consistent with models of endogenous fertility (e.g. [Barro and Sala-i-Martin, 1995](#), [Ch. 9]) the coefficient on fertility rate is negative and significant, while the negative coefficient on government consumption supports the view that unproductive government spending is harmful for growth. As expected, the impact of inflation on growth is negative, while trade and foreign direct investment display the expected positive signs. Similar to the findings of [Doucouliagos and Paldam \(2009\)](#); [Chervin and van Wijnbergen \(2010\)](#), and [Dalgaard et al. \(2004\)](#), the coefficient on net official development assistance and official aid received is negative and significant. [Doucouliagos and Paldam \(2009\)](#) survey over 97 articles on the relationship between aid and growth and note that "after 40 years of development aid, the preponderance of the evidence indicates that aid has not been effective" (pp. 433). They conclude that the Dutch disease effect on exchange rates possibly explains some of the observed ineffectiveness of foreign aid. [Chervin and van Wijnbergen \(2010\)](#) point to the problem of aid volatility as an obstacle for economic growth, reporting that volatile aid flows tend to have a negative and significant impact on economic growth. [Dalgaard et al. \(2004\)](#) finds that aid has been less effective in tropical countries, explaining that there might be misguided aid effects due to the amount of aid being used for humanitarian purposes rather than investment, diversion of aid due to corruption within the recipient country, or ineffective macroeconomic policy environment to channel aid to productive investment. The negative coefficient on life expectancy across all specifications was rather surprising. [Cervellati and Sunde \(2011\)](#), however, argue that the impact of life expectancy on economic growth depends on whether the country has already experienced a demographic transition, and can vary depending on a country's level of development.

The results in the rest of the paper are estimated using the two-step System GMM estimator, so before proceeding, we conduct further robustness checks to ensure that this specification is valid. One frequently cited weakness of the two-step system estimator is that its standard errors generally tend to suffer a downward finite sample bias ([Arellano and Bond, 1991](#); [Blundell and Bond, 1998](#)). While we do not believe this is a problem in the current paper as all two-step estimations employ the [Windmeijer \(2005\)](#) small sample correction to the standard errors, it is worthwhile examining the one-step GMM results as well (column 4 of [Table 2](#)). Results show that the impact of electricity generation on growth is still positive and significant. Furthermore, the signs and

Table 2
The impact of electricity generation on economic growth.

Variables	(1) OLS	(2) Fixed Effect	(3) SYSGMM1	(4) SYSGMM2	(5) SYSGMM3
Lagged GDP per capita	–1.0201*** (0.181)	–5.3194*** (0.665)	–1.5381** (0.470)	–1.0816*** (0.188)	–0.8753*** (0.034)
Total Electricity	0.05847*** (0.012)	0.0539*** (0.012)	0.1014** (0.027)	0.1272*** (0.014)	0.1313*** (0.004)
Primary enrollment	–0.0061 (0.007)	–0.0220 (0.013)	0.0059 (0.019)	–0.0015 (0.007)	–0.0039 (0.003)
Life Expectancy	–0.0157 (0.022)	0.0895 (0.056)	–0.1325** (0.039)	–0.05591** (0.027)	0.04037*** (0.004)
Foreign aid (log)	0.1206 (0.106)	0.2482 (0.175)	–0.7292** (0.363)	–0.1070 (0.120)	0.2298*** (0.020)
Trade	0.0149*** (0.004)	0.0082** (0.004)	0.0436*** (0.007)	0.0429*** (0.006)	0.0294*** (0.002)
Inflation	–0.0014*** (0.000)	–0.0011*** (0.000)	–0.0013 (0.001)	–0.0009*** (0.000)	–0.0006** (0.000)
Government	–0.0551** (0.023)	–0.0971** (0.035)	–0.2487** (0.078)	–0.1628*** (0.033)	–0.1776*** (0.017)
Fertility rate (log)	–4.1252*** (0.462)	1.5564 (1.366)	–5.2686*** (0.871)	–4.4495*** (0.533)	–1.9218*** (0.169)
FDI	0.1792*** (0.029)	0.1321** (0.036)	0.3410*** (0.077)	0.2914*** (0.035)	0.3672*** (0.013)
Savings rate	0.0559*** (0.011)	0.0843*** (0.017)	0.0815** (0.028)	0.0796*** (0.014)	0.1058*** (0.004)
Intercept	11.049** (3.472)	32.558*** (7.669)			
AR (2) test			–2.5100 [0.012]	–1.5400 [0.123]	–1.5200 [0.128]
Hansen test			33.2900 [1.000]	32.1300 [1.000]	64.8100 [1.000]

Notes: Standard errors in parentheses; p-values in brackets. ***, **, *, indicate significance at the 1%, 5%, and 10% levels respectively.

significance of the coefficients on most of the other control variables remain unchanged. The AR(2) test still shows no significant evidence of second-order serial correlation in the first-differenced residuals, while the Hansen test indicates that the instruments remain valid. In column 5, we re-estimate the two-step GMM model without year effects. As the results show, the estimated impact of electricity generation remains positive and significant. However, the coefficient on the lag endogenous variable no longer falls in the credible range between the OLS and fixed effects estimates. These sensitivity analyses give us some degree of confidence that the two-step GMM model with year effects (column 3) is more appropriate. As a consequence, the results in the remainder of the paper are all estimated using the two-step system estimator.

3.2. Renewable and nonrenewable electricity generation

After examining the effect of total electricity generation on economic growth, we now disaggregate total electricity generation into renewable and nonrenewable generation and examine their impacts on growth. Over the past three decades, there has been a surge in global renewable electricity generation, particularly in advanced economies, yet nonrenewable electricity remains the dominant source of electricity generation for most countries. It would be interesting to investigate whether the positive impact of electricity generation is driven by growth in nonrenewables, renewables or both, as the findings could have significant policy implications.

Table 3 shows the results for renewable and nonrenewable electricity generation based on two-step System GMM estimation. In column 1, we include renewable electricity generation as the only electricity source in our growth model. The coefficient on renewable electricity generation is positive at 0.03 and with a standard error of 0.01 is highly significant. When we include only nonrenewable electricity generation in the model (column 2), we also find a positive and significant impact on economic growth. Because both renewable and nonrenewable electricity generation affect economic growth (as shown

above), and since the two are presumably not independent, to estimate the effects of one, it is also necessary to include the other. Hence, column 3 of Table 3 estimates the growth model with both renewable and nonrenewable generation included in the regression. The coefficient on both variables is positive and significant, but while that of renewables remains the same as in column 1, the coefficient on non-renewables almost doubles. It is also important to note that across all three specifications, the signs and significance of the coefficients on the other explanatory variables remain as previously found. Furthermore, the tests for serial correlation continue to show no evidence of second- or higher-order serial correlation in the first-differenced residuals, while the tests for overidentification indicate that the instruments are valid.

So far, we have utilized data on renewable and nonrenewable electricity generation from the Energy Information Administration. The World Bank provides an alternative dataset on renewable and non-renewable electricity output as a percent of total electricity production. Unfortunately, this data on renewable electricity output as a percentage of total electricity output is only available for the period 1990–2012. Results using these measures of electricity generation are available in the last three columns of Table 3. In column 4, we see that the coefficient on renewable output share is 0.019 and is significant at the 1% level, while that on nonrenewable electricity output as a share of total electricity production (column 5) is still positive and significant, albeit only at the 10% level of significance. When both are included in the model, the coefficient is unchanged for renewable electricity, while the coefficient for nonrenewable electricity is much smaller at 0.004. The finding that renewable and nonrenewable electricity generation both enhance growth is consistent with the work of Verdolini et al. (2016), who find that fossil fuel generation is needed as a support mechanism to assist in the development of renewable electricity generation. Their results on 26 OECD countries using data for the period 1990–2013 show that a 1% increase in the proportion of fast-reacting fossil fuel generation is associated with a 0.88% increase in renewables. Their finding

Table 3
The impact of renewable and nonrenewable electricity generation on economic growth.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Lagged GDP per capita	−1.4937*** (0.359)	−2.4402*** (0.582)	−2.2487*** (0.546)	−1.0732** (0.267)	−0.9731 (0.591)	−1.2501*** (0.286)	−1.2320* (0.731)
Renewable (EIA data)	0.0328** (0.010)		0.0338** (0.013)				0.0383* (0.021)
Nonrenewable (EIA data)		0.0197** (0.006)	0.0366** (0.009)				0.0425** (0.016)
Renewable (World Bank data)				0.0192** (0.007)		0.0173* (0.009)	
Nonrenewable (World Bank data)					0.0211* (0.012)	0.0045* (0.002)	
Electricity Loss							−0.0170 (0.007)
Primary enrollment	0.0143 (0.018)	−0.0252 (0.017)	−0.0425** (0.018)	0.0124 (0.014)	−0.0345* (0.020)	0.0045 (0.012)	−0.0499** (0.023)
Life expectancy	−0.1486** (0.045)	−0.0913** (0.042)	−0.1151** (0.043)	−0.1223** (0.038)	−0.2030** (0.052)	−0.0965* (0.057)	−0.1519** (0.052)
Foreign aid (log)	−0.5152** (0.250)	−0.6985* (0.366)	−0.5356 (0.353)	−0.0596 (0.155)	−0.4949 (0.315)	−0.2424 (0.171)	−0.2242 (0.628)
Trade	0.0517*** (0.009)	0.0294** (0.008)	0.0370** (0.009)	0.0454*** (0.005)	−0.0008 (0.007)	0.0334*** (0.007)	0.0285* (0.015)
Inflation rate	−0.0016 (0.001)	−0.0026** (0.001)	−0.0009 (0.001)	−0.0003 (0.001)	−0.0022 (0.001)	−0.0048* (0.003)	0.0007 (0.002)
Government	−0.2467** (0.069)	−0.0491 (0.054)	0.0149 (0.071)	−0.2020*** (0.042)	0.0704 (0.067)	−0.2270** (0.080)	−0.0066 (0.085)
Fertility rate (log)	−6.1242*** (0.917)	−5.2880*** (0.957)	−6.4048*** (1.316)	−5.9615*** (0.781)	−6.0966*** (1.195)	−6.0459*** (0.792)	−6.3758*** (1.322)
FDI	0.3342** (0.101)	0.3052** (0.076)	0.3198** (0.095)	0.2710*** (0.042)	0.0684 (0.099)	0.0518 (0.054)	0.3409** (0.132)
Savings rate	0.0653** (0.031)	0.0994** (0.026)	0.0787* (0.040)	0.0608* (0.025)	0.0679* (0.035)	0.0686*** (0.016)	0.0718 (0.054)
AR (2) test	0.2400 [0.810]	−1.0300 [0.303]	−1.0300 [0.301]	−1.3000 [0.192]	−1.4800 [0.139]	−1.5800 [0.115]	−1.2800 [0.202]
Hansen test	33.8500 [1.000]	44.5100 [1.000]	37.7100 [1.000]	48.6100 [1.000]	29.5400 [1.000]	40.6800 [1.000]	25.7600 [1.000]

Notes: Standard errors in parentheses; p-values in brackets. ***, **, *, indicate significance at the 1%, 5%, and 10% levels respectively.

points to the notion that there is a complementary relationship between renewables and fast-reacting fossil fuel generation sources, as they can be used as back-up when the renewable electricity source is unreliable.

One major challenge that many nations face is power loss in the transmission and distribution to the end user. Not all of the power generated by power plants will be able to travel over long distances to the final consumers, as there will be technical losses due to energy losses in transmission. Not only do technical challenges pose an obstacle in power losses, but electricity theft has emerged as a major source of power losses, especially in developing countries. In India for example, more than 30% of electricity generated is lost due to theft and inefficiencies in the transmission and distribution system (Gaur and Gupta, 2016). As a result, in column 6, we include a measure of electricity transmission and distribution losses into the model to examine its effect on economic growth. The sign on electricity loss is negative and significant, suggesting that transmission and distribution losses are harmful for growth. As before, the coefficients on renewable and non-renewable electricity generation are positive. The finding that losses in transmission and distribution of electricity have a negative impact on economic growth is consistent with Gaur and Gupta (2016) who find that the losses that result from electricity theft in India decrease India's GDP by approximately 1.5%. Steadman (2009) reports a similar result for Jamaica.

3.3. Discussion and implications for the future of electricity

The results presented above point to a positive relationship between electricity generation and economic growth. When we disaggregate total generation into renewable and nonrenewable electricity

generation, we see that they each have significant growth-enhancing effects. The results highlight the progress that renewable electricity has made in becoming a larger player in the electricity portfolio of many countries, however, they also highlight the continued dominance of fossil fuel-based generation. In many countries, the pursuit of a diverse electricity generation portfolio also stems from the drive to ensure energy security. According to the World Bank, worldwide electricity production from coal increased from 32.9% in 1980 to 40.3% in 2012,⁴ while worldwide electricity production from natural gas rose from 8.9% in 1980 to 22.4% in 2012.⁵ Furthermore, anticipated growth rates for natural gas fired electricity generation are projected to be an average increase of 2.7% per year from 2012 to 2040, as many countries are turning to natural gas as a means to achieve carbon emission reduction goals and their efficiency compared to coal fired plants (Energy Information Administration, 2016).

With ever-increasing concerns about climate change resulting from greenhouse gas emissions, our findings have important implications for the future of electricity generation and its relationship with economic growth. The finding that renewable electricity generation has a positive relationship with growth implies that countries which currently rely on nonrenewable or perhaps more risky forms of electricity can transition to renewable, cleaner, or less risky forms of electricity generation without necessarily hindering economic growth. For example, after the devastating earthquake and tsunami that led to the Fukushima nuclear disaster and subsequent suspension of their nuclear power plants, Japan began transitioning from nuclear power as the main source of electricity

⁴ <http://data.worldbank.org/indicator/EG.ELC.COAL.ZS>.

⁵ <http://data.worldbank.org/indicator/EG.ELC.NGAS.ZS>.

to making coal the foundation of their energy portfolio as a means to provide electricity. On the other hand, in response to the Chernobyl nuclear disaster of 1986, Germany witnessed a rise in environmental consciousness and significant opposition to nuclear power (Lauber and Mez, 2004), causing Germany to implement numerous policies to stimulate the growth of renewable electricity across the country. In 1991, their 1000 Solar Roofs Program led to the installation of over 2000 grid-connected photovoltaic (PV) systems on Germany's rooftops. This successful program later expanded to the 100,000 Roofs Program to drive PV electricity generation such that by the program's end in 2004, 100,000 grid-connected rooftop solar systems had been successfully installed in Germany (Lauber and Mez, 2004). Germany also implemented a Feed-In Law which was crucial in helping to make wind more cost competitive and brought private investors into the market and Germany saw a rise in wind power from 20 MW in 1989–1100 MW in 2005. These policies were significant for renewable electricity generation not only because it saw the country pursue the path of renewable electricity generation, but as our results show, can also be beneficial for economic growth.

The finding of a negative relationship between electricity loss and economic growth has significant implications for the future of electricity generation, as well. As mentioned earlier, transmission and distribution losses, together with electricity theft have emerged as major sources of power losses. The rise in electricity theft has resulted in a vicious cycle where systems are compromised by the stress placed on the system by the number of unmetered users. Utility providers lose revenue and therefore are unable to make needed investments to upgrade the transmission and distribution infrastructure. Jamil (2013) reports that between 1985 and 2010, electricity theft largely impacted electricity deficits through a decrease in investment and inefficient use of electricity and caused higher electricity prices. Not only could utilities not make investments in additional capacity, but Jamil (2013) finds that the individuals stealing electricity have no incentive to be conservative in their electricity use, leading to inefficient use, and utility providers end up relying on subsidies from the government, thereby crowding out private investment and economic growth. Electricity outages resulting from transmission and distribution losses, theft and poor electricity infrastructure also harm economic growth because businesses have to make investments in back-up power sources, and when these investments are huge, this may discourage potential entrepreneurs from starting new businesses, or cause current entrepreneurs to shut down (Foster and Steinbuks, 2009). Foster and Steinbuks (2009) and Andersen and Dalgaard (2013) report a substantial growth drag of a weak power infrastructure in Sub-Saharan Africa, finding that a 1% increase in outages decreases long run GDP per capita by 2.86%. Eberhard et al. (2011) estimate that power outages in countries in Sub-Saharan Africa translate to an average decrease in GDP of 2.1%, while Shahbaz (2015) shows that for Pakistan, the negative impact of electricity outages on GDP may be as high as 10%. Our results on the effects of electricity loss complement previous findings, and emphasize the need for countries to pursue policies aimed at reducing electricity losses due to transmission and distribution losses, theft, and outages as these policies can have significant growth-enhancing effects.

4. Conclusion and policy implications

Extensive research has examined the relationship between

electricity and economic growth. Much of that research has focused on the effect of electricity consumption on growth. However, because of transmission and distribution losses, theft, and electricity exports, not all the electricity that is generated is eventually consumed. Accordingly, this paper looks at the relationship between electricity generation and economic growth using data for a panel of 174 countries over the period 1980–2012. We also control for the effects of education, trade, government consumption, and other economic and social factors that directly affect growth. To deal with potential endogeneity issues, given that electricity generation and many of the other regressors may be jointly determined with GDP growth, we estimate the impact of electricity generation on economic growth using the System Generalized Methods of Moments (GMM) approach. We test the validity of the orthogonality assumptions underlying the System GMM estimator using the Hansen test of overidentification and the Arellano and Bond test of second-order serial correlation, and employ the Windmeijer (2005) small sample correction of the standard errors in all two-step System GMM estimations.

While much of the existing literature on the relationship between electricity and economic growth relationship has documented conflicting evidence, our baseline results, as well as a battery of robustness checks consistently display evidence of a positive and significant relationship between renewable and nonrenewable electricity generation and economic growth. Over the past decade, many countries have integrated renewable sources in their electricity grid as a means to reduce carbon emissions and potentially address climate change. One major concern for these countries when addressing the integration of renewable energy is that it could be detrimental to economic growth. The finding that renewable and nonrenewable electricity generation each have positive impacts on growth suggests that countries can employ policies that help them transition to renewable or (cleaner) non-renewable sources in the pursuit of their environmental objectives, while simultaneously enhancing economic growth. Furthermore, the finding that power losses, whether from an inefficient electricity grid, poor electricity infrastructure, or theft, have a statistically significant negative relationship with economic growth is also important from a policy perspective. This suggests that it is crucial for countries to develop policy strategies to tackle this issue, such as those encouraging higher investment in the electricity transmission and distribution grid, the development of microgrids or minigrids in remote areas to reduce transmission and distribution losses that result from long distances between generation and consumption sites, and a focus on limiting electricity theft from consumers.

We believe that the findings of this paper extend current understanding of the link between electricity generation and economic growth, yet the importance of this relationship requires that more work needs to be done on this topic. In the current paper, we examine the growth effects of aggregate renewable and nonrenewable electricity generation. Perhaps future research efforts could disentangle the aggregate measures into more disaggregate measures, as not all renewable and nonrenewable electricity sources are expected to have similar impacts on economic growth. Furthermore, future research could explore asymmetries in the effects of renewable and nonrenewable electricity on growth based on countries' levels of economic development (e.g. between developing and developed countries).

Appendix

Table 4

Table 4
Countries in the sample.

Afghanistan	Cameroon	Gabon	Kyrgyzstan	Niger	Spain
Albania	Canada	Gambia	Laos	Nigeria	Sri Lanka
Algeria	Central African Republic	Georgia	Latvia	Norway	Suriname
Angola	Chad	Germany	Lebanon	Oman	Swaziland
Antigua & Barbuda	Chile	Ghana	Lesotho	Pakistan	Sweden
Argentina	China	Greece	Liberia	Panama	Switzerland
Armenia	Colombia	Grenada	Libya	Papua New Guinea	Syria
Australia	Comoros	Guatemala	Lithuania	Paraguay	Tajikistan
Austria	Costa Rica	Guinea	Luxembourg	Peru	Tanzania
Azerbaijan	Cote d'Ivoire	Guinea Bissau	Macau	Philippines	Thailand
Bahamas	Croatia	Guyana	Macedonia	Poland	Togo
Bahrain	Cuba	Haiti	Madagascar	Portugal	Tonga
Bangladesh	Cyprus	Honduras	Malawi	Puerto Rico	Trinidad & Tobago
Barbados	Czech Republic	Hong Kong	Malaysia	Republic of Congo	Tunisia
Belarus	DR Congo	Hungary	Mali	Russia	Turkey
Belgium	Denmark	Iceland	Malta	Rwanda	Turkmenistan
Belize	Djibouti	India	Mauritania	Samoa	Uganda
Benin	Dominica	Indonesia	Mauritius	Sao Tome & Principe	Ukraine
Bhutan	Dominican Republic	Iran	Mexico	Saudi Arabia	United Arab Emirates
Bolivia	Ecuador	Iraq	Moldova	Senegal	United Kingdom
Bosnia Herzegovina	Egypt	Ireland	Mongolia	Serbia	United States
Botswana	El Salvador	Israel	Morocco	Seychelles	Uruguay
Brazil	Equatorial Guinea	Italy	Mozambique	Sierra Leone	Uzbekistan
Brunei	Eritrea	Jamaica	Myanmar	Singapore	Vanuatu
Bulgaria	Estonia	Japan	Namibia	Slovakia	Venezuela
Burkina Faso	Ethiopia	Jordan	Nepal	Slovenia	Vietnam
Burundi	Fiji	Kazakhstan	Netherlands	Solomon Islands	Yemen
Cabo Verde	Finland	Kenya	New Zealand	South Africa	Zambia
Cambodia	France	Kuwait	Nicaragua	South Korea	Zimbabwe

References

- Acaravci, A., Ozturk, I., 2010. Electricity consumption-growth nexus: evidence from panel data for transition countries. *Energy Econ.* 32 (3), 604–608.
- Alesina, A., Dollar, D., 2000. Who gives foreign aid to Whom and why? *J. Econ. Growth* 5 (1), 33–63.
- Al-mulali, U., Fereidouni, H.G., Lee, J.Y., 2014. Electricity consumption from renewable and non-renewable sources and economic growth: Evidence from Latin American countries. *Renew. Sustain. Energy Rev.* 30, 290–298.
- Andersen, T.B., Dalgaard, C.J., 2013. Power outages and economic growth in Africa. *Energy Econ.* 38, 19–23.
- Apergis, N., Danuletiu, D.C., 2014. Renewable energy and economic growth: evidence from the sign of panel long-run causality. *Int. J. Energy Econ. Policy* 4 (4), 578.
- Apergis, N., Payne, J.E., 2010. Renewable energy consumption and growth in Eurasia. *Energy Econ.* 32 (6), 1392–1397.
- Apergis, N., Payne, J.E., 2011a. A dynamic panel study of economic development and the electricity consumption-growth nexus. *Energy Econ.* 33 (5), 770–781.
- Apergis, N., Payne, J.E., 2011b. The renewable energy consumption- growth nexus in Central America. *Appl. Energy* 88 (1), 343–347.
- Apergis, N., Payne, J.E., 2012. Renewable and non-renewable energy consumption-growth nexus: evidence from a panel error correction model. *Energy Econ.* 34 (3), 733–738.
- Arellano, M., Bond, S., 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Rev. Econ. Stud.* 58 (2), 277–297.
- Arellano, M., Bover, O., 1995. Another look at the instrumental variable estimation of error-components models. *J. Econ.* 68 (1), 29–51.
- Badunenko, O., Romero-Ávila, D., 2013. Financial development and the sources of growth and convergence. *Int. Econ. Rev.* 54 (2), 629–663.
- Barro, R.J., 2003. Determinants of economic growth in a panel of countries. *Ann. Econ. Financ.* 4, 231–274.
- Barro, R.J., Sala-i-Martin, X., 1991. Convergence across states and regions. *Brook. Pap. Econ. Act.* 107–182.
- Barro, R.J., Sala-i-Martin, X., 1992. Convergence. *J. Political Econ.* 100 (2), 223–251.
- Barro, R.J., Sala-i-Martin, X., 1995. *Economic Growth Theory*. McGraw-Hill, New York.
- Barro, R.J., 1996. Determinants of economic growth: a cross-country empirical study (No. w5698). National Bureau of Economic Research.
- Becker, G., Barro, R., 1988. A reformulation of the economic theory of fertility. *Q. J. Econ.* 103 (1), 1–25.
- Blundell, R., Bond, S., 1998. Initial conditions and moment restrictions in dynamic panel data models. *J. Econ.* 87 (1), 115–143.
- Blundell, R., Bond, S., 2000. GMM estimation with persistent panel data: an application to production functions. *Econ. Rev.* 19 (3), 321–340.
- Bond, S., 2002. Dynamic panel data models: a guide to micro data methods and practice. *Port. Econ. J.* 1 (2), 141–162.
- Bond, S., Hoeffler, A., Temple, J., 2001. *GMM Estimation of Empirical Growth Models*. Working Paper.
- Briault, C., 1995. The costs of inflation. *Bank Engl. Q. Bull.* 35 (1), 33–45.
- Brühlhart, M., Mathys, N., 2008. Sectoral agglomeration economies in a panel of European regions. *Reg. Sci. Urban Econ.* 38, 348–362.
- Cervellati, M., Sunde, U., 2011. Life expectancy and economic growth: the role of the demographic transition. *J. Econ. Growth* 16 (2), 99–133.
- Chervin, M., van Wijnbergen, S., 2010. *Economic Growth and the Volatility of Foreign Aid* (No. 10-002/2). Tinbergen Institute.
- Dalgaard, C.J., Hansen, H., Tarp, F., 2004. On the empirics of foreign aid and growth. *Econ. J.* 114 (496), F191–F216.
- Depuru, S.S.S.R., Wang, L., Devabhaktuni, V., 2011. Electricity theft: overview, issues, prevention and a smart meter based approach to control theft: overview, issues, prevention and a smart meter based approach to control theft. *Energy Policy* 39 (2), 1007–1015.
- Dollar, D., Pritchett, L., 1998. Assessing aid - what works, what doesn't, and why. World Bank policy research report. Washington, DC: The World Bank.
- Doucouliagos, H., Paldam, M., 2009. The aid effectiveness literature: the sad results of 40 years of research. *J. Econ. Surv.* 23 (3), 433–461.
- Eberhard, A., Rosnes, O., Shkaratan, M., Vennemo, H., 2011. *Africa's Power Infrastructure: Investment, Integration, Efficiency*. World Bank Publications.
- Energy Information Administration, 2016. *International Energy Outlook*. U.S. Energy Information Administration: Washington, DC. Retrieved from <<http://www.eia.gov/outlooks/ieo/>>.
- Foster, V., Steinbuks, J., 2009. Paying the price for unreliable power supplies: in-house generation of electricity by firms in Africa. World Bank Policy Research Working Paper Series.
- Gaur, V., Gupta, E., 2016. The determinants of electricity theft: an empirical analysis of Indian states. *Energy Policy* 93, 127–136.
- Halkos, G.E., Tzeremes, N.G., 2014. The effect of electricity consumption from renewable sources on countries economic growth levels: evidence from advanced, emerging and developing economies. *Renew. Sustain. Energy Rev.* 39, 166–173.
- Hsiao, C., 1986. *Analysis of Panel Data*. Cambridge University Press, New York.
- Jamil, F., 2013. On the electricity shortage, price and electricity theft nexus. *Energy Policy* 54, 267–272.
- Kraft, J., Kraft, A., 1978. Relationship between energy and GNP. *J. Energy Dev.* 3, 2.
- Lauber, V., Mez, L., 2004. Three decades of renewable electricity policies in Germany. *Energy Environ.* 15 (4), 599–623.
- Pao, H.T., Fu, H.C., 2013. Renewable energy, non-renewable energy and economic growth in Brazil. *Renew. Sustain. Energy Rev.* 25, 381–392.
- Pritchett, L., 2001. Where has all the education gone? *World Bank Econ. Rev.* 15 (3), 367–391.
- Sala-i-Martin, X.X., 1997. I just ran two million regressions. *Am. Econ. Rev.* 178–183.
- Shahbaz, M., 2015. Measuring Economic Cost of Electricity Shortage: Current Challenges and Future Prospects in Pakistan.
- Steadman, K., 2009. *Electricity Theft in Jamaica*. State University of New York, Binghamton.
- Verdolini, E., Vona, F., Popp, D., 2016. Bridging the Gap: Do Fast Reacting Fossil Technologies Facilitate Renewable Energy Diffusion? (No. w22454). National Bureau of Economic Research.
- Windmeijer, F., 2005. A finite sample correction for the variance of linear efficient two-step GMM estimators. *J. Econ.* 126 (1), 25–51.