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Economic growth and electricity consumption

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Abstract

Do countries consume more electricity as they become richer? This study uses an instrumental variables approach to investigate the connection between electricity consumption and economic growth. With panel data of 32 countries spanning the period of 1996-2014, two potential instruments, which are an oil price shock as the main focus and past saving rates, are used for estimation. Controlling for country and time-fixed effects, the estimation results show no evidence of unidirectional causality runs from national income to electricity consumption.

Keywords: Electricity consumption, Economic development

1. Introduction

In the last 40 years, the world has witnessed an unprecedented rise in electric power consumption. From World Bank (2018) online database, in 1974 one person consumed around 1345.8 kWh of electricity a year. Forty years later, the number has doubled to 3127.4 kWh. While electricity consumption is considered an indicator of socio-economic growth, many development practitioners are concerned about the environmental problems that production of electricity brings about. The relationship between economic growth and electricity consumption has long been an important topic for research. Many works have focused on the direction of causality between these two factors, but the results are still unclear. Understanding this relationship is crucial in the planning and application of energy and environmental policies.

Ozturk and Acaravci (2011) categorized the causal relationship between economic growth and electricity consumption into four hypotheses: "(1) Neutrality hypothesis: The neutrality hypothesis is supported by the absence of a causal relationship between electricity consumption and real GDP. The neutrality hypothesis states that electricity conservation policies will have no effect on economic growth. (2) Conservation hypothesis: It is also called unidirectional causality running from economic growth to electricity consumption. If

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such is the case, electricity conservation policies designed to reduce electricity consumption and waste will have little or no effect on economic growth. (3) Growth hypothesis: It implies that causality runs from electricity consumption to economic growth. The growth hypothesis suggests that electricity consumption plays an important role in economic growth. In this case, the reduction in electricity consumption due to electricity conservation-oriented policies may have a detrimental impact on economic growth. (4) Feedback hypothesis: It implies that there is two-way (bidirectional) causality between electricity consumption and economic growth."

In a survey of the empirical literature, Payne (2010) showed that in various studies surveyed, "31.15% supported the neutrality hypothesis; 27.87% the conservation hypothesis; 22.95% the growth hypothesis; and 18.03% the feedback hypothesis."

The purpose of this paper is to answer the question: is there a unidirectional causality running from national income to electricity consumption. Estimating causal effects of economic growth on electricity consumption is complicated by the endogeneity of the former. It is predicted in many macroeconomic models that an increase in electricity consumption will raise total output by adding to aggregate supply, although the size of the effect depends on the model. Furthermore, beyond this possible reverse causality running from electricity consumption to national income, omitted variables are also a major problem. Therefore, to estimate the causal effects of economic growth on electricity consumption, we use panel data and the instrumental variables approach. We control for within-country time-invariant factors and global business-cycle that affect both electricity consumption and national income by adding country and year-fixed effects. Time-invariant characteristics such as country-specific historical and human factors may have effects on both electricity consumption and income, and the inclusion of country-fixed effects will parallel out this bias. Controlling for year-fixed effects helps remove the global trend that affects both variables.

Our first result shows that even when country and year fixed effects are included, there still exists a positive and statistically significant effect between GDP per capita and electricity consumption. While the estimate with country and year fixed effects removes time-invariant determinants of both electricity consumption and national income and the global trend, it may not capture the causal effect of GDP per capita growth on electricity consumption because of reverse causality and omitted time-variant variables biases. That is why we use the instrumental variables (IV) approach to estimate the effect of national income on electricity consumption. We run estimations with two potential instrumental variables. The first instrument is a country-specific oil price shock variable, which is the logarithm of the growth rate of the international oil price-weighted with the average proportion of oil net export in GDP of each country in the period of 1996-2014. Oil price shock has been employed as an instrument for the GDP of countries in other studies (Brückner *et al.*, 2012; Brückner and Schwandt, 2013; Acemoglu *et al.*, 2013), but it has not been used before to study how economic growth affects electricity consumption. The second variable we use is past savings rates (Acemoglu *et al.*, 2008). The instrumental variable has a strong first-stage relationship with GDP per capita, and it should not directly affect electricity consumption. The results of both IV estimations indicate that there is no causality running from income to electricity consumption. None of the instruments is flawless because there are circumstances in which the exclusion restrictions can be violated. For example, saving rates might be determined by energy policies that affect electricity consumption. However, we will discuss some factors that may violate the exclusion restriction and provide proofs that the exclusion restriction is still valid.

The rest of this paper is organized as follows. Section 2 contains the literature review. Section 3 presents the description of the data and the estimation strategies. Section 4 shows the main empirical results and Section 5 concludes the paper.

2. Literature review

Many researchers come up with different results while studying the relationship between electricity consumption and economic growth in different countries with several methods. Mehrara (2007) notes that there are four generations of studies. The first generation of studies is based on the traditional vector autoregression (VAR) methodology (Sims, 1972) and Granger's test for causality (Granger, 1969). Because these studies make an assumption of stationarity in the data used, their results are suspicious. The second and third generations acknowledge that the variables could be non-stationary. Therefore, the cointegration method is more appropriate to study the relationship between economic growth and electricity consumption. The second generation follows Granger's (1988) two stages process. The first stage is testing for a cointegration relationship. If such a relationship exists, it allows for testing of Granger causality by using an estimated error correction model. The third generation uses multivariate estimators. The fourth generation of studies based on panel cointegration and panel error correction model. The econometric techniques used for these studies have become more complicated, but the results remain inconclusive.

For the first generation, Granger (1969), and Granger and Newbold (1974) note that the stationary of time series is the required condition for the Granger-causality test. Therefore, unit root tests are necessary to find out whether the time series is stationary by nature or stationary after first differencing. Murray and Nan (1996) employ this standard causality test with data from 15 countries from 1970 to 1990. Their analysis shows that the neutrality hypothesis is valid in the Philippines, India, and Zambia; the conservation hypothesis holds in Indonesia, El Salvador, Colombia, and Kenya; and the growth hypothesis is supported in Pakistan, Canada, Singapore, Malaysia, Mexico, Hong Kong, South Korea, and Turkey. Narayan and Prasad (2008) also employ the standard bootstrap Granger causality test on 30 OECD countries without explicitly testing for cointegration and confirmed conservation hypothesis. However, Perron (1989) states that structural breaks in time series must be taken into account. Otherwise, the null hypothesis of unit root might not be rejected when time series is in fact stationary when included structural break. Altinay and Karagol (2005) include structural break and find the integration of order zero between variables, which supports the growth hypothesis. In another study, Narayan and Smyth (2005) employ Zivot and Andrews's (1992) unit root test with an endogenously determined structural break to find out integration of order one in variables and conclude that in the long-run real income and employment Granger cause electricity consumption. There is, however, weak causality running from income to electricity usage and income to employment in the short run.

The second generation has started when Engle and Granger (1987) develop the standard Granger-causality tests to include cointegration of two-time series, which allow for testing the Granger causality in an error correction model. Aqeel and Butt (2001), Morimoto and Hope (2004), Thoma (2004), Yang (2000), and Yoo and Kim (2006) do not find cointegration and, therefore, run Granger causality tests in a vector autoregressive framework. Findings from Morimoto and Hope (2004), Yoo and Kim (2006), and Aqeel and Butt (2001) support the growth hypothesis in Sri Lanka and Indonesia. Results from Thoma (2004) support the conservation hypothesis. The feedback hypothesis is confirmed by Yang (2000) in Taiwan. Jumbe (2004) finds cointegration between variables, tests for Granger causality within a vector error correction model and discovers unidirectional causal effect running from GDP and NGDP to electricity consumption in Malawi.

For the third generation, Johansen (1988), and Johansen and Juselius (1990) employ a multivariate cointegration procedure that can address concerns in the Engle-Granger method. This is the most common approach when investigating the causal effect between national income and electricity usage. Ghosh (2002) and Yoo (2006) use this approach but do not find cointegration between variables. Ghosh (2002) finds supports the conservation hypothesis in India from 1950 to 1996, while Yoo (2006) supports the feedback hypothesis in Singapore and Malaysia, and the growth hypothesis in Thailand and Indonesia. In contrast, Shiu and Lam (2004), Mozumder and Marathe (2007), Yoo (2005), Chen *et al.* (2007), Ho and Siu (2007), and Yuan *et al.* (2007) find cointegration between variables and use a vector error correction model to test for Granger causality. The growth hypothesis is supported by the study of Shiu and Lam (2004) in China, the study of Yuan *et al.* (2007) in China, and the study of Ho and Siu (2007) in Hong Kong. In contrast, Mozumder and Marathe (2007) support the conservation hypothesis in Bangladesh. Yoo (2005) finds feedback effects between two variables in Korea. Chen *et al.* (2007) examine 10 ASEAN countries in the period of 1971-2001 and also find feedback effects. Apergis and Payne (2011) also use a multivariate production function with panel data from 88 countries to zoom in on the relationship between economic growth and electricity usage. They use a panel error correction model and address a bidirectional causality between two variables for upper-middle-income and high-income country panels, meanwhile a growth hypothesis exists in the low-income country panels.

The final generation begins with the studies about panel cointegration tests by Westerlund (2006), Pedroni (1999), and Pedroni (2004) to solve the limitation of data problem in various studies, which make unit root and cointegration tests less accurate, by allowing for heterogeneity across countries' panel data. Narayan and Smyth (2009), and Chen *et al.* (2007) find cointegration using this panel cointegration process. Narayan and Smyth (2009) find a significant bidirectional causal effect between GDP, export, and electricity usage in Middle Eastern countries. Ozturk and Acaravci (2011) investigate 15 transition economies with a panel cointegration approach, and find no cointegration between two variables and suggested energy conservation policies will badly affect economic development. Ciarreta and Zarraga (2008) find that electricity usage determines economic growth in the long run in European economies by using causality and panel cointegration approaches. Wolde-Rufael (2014) uses the bootstrap panel cointegration test. Their results show that electricity usage has significant effects on national income in Belarus and Bulgaria; economic growth leads to energy usage in Lithuania, Czech Republic, Latvia; and bidirectional causality between two variables in Ukraine and the Russian Federation.

All four generations of studies depend heavily on the pre-testing for unit root and cointegration, which may suffer from size distortions. Therefore, some econometric procedures have been proposed to avoid biases of pre-testing in the causality test. These procedures are autoregressive distributed lag (ARDL) and bounds testing introduced by Pesaran and Shin (1999), Pesaran *et al.* (2001), and Toda and Yamatomo (1995).

The ARDL approach is suitable for studies with a small sample, which is often the case of economic growth and electricity consumption studies. Moreover, it allows for estimating short-run and long-run effects simultaneously within the vector error correction model. Ghosh (2009), Narayan and Smyth (2005), Squalli (2007), and Narayan and Singh (2007) find cointegration using ARDL bound testing approach, while Tang (2008) does not. Narayan and Singh (2007) employ the multivariate production function by adding labor as a determinant of electricity consumption and economic advancement for Fiji Island from 1971 to 2002 and find unidirectional causality running from national income to electricity consumption. Squalli (2007) shows the dependence of economic development on electricity usage in OPEC countries. Ghosh (2009) confirms there is no causality running from electricity consumption to real GDP in India from 1970 to 2005. Tang (2008) confirms the feedback hypothesis in Malaysia from 1972 to 2003.

The Toda-Yamamoto approach provides long-run information and allows for inferring causality using the VAR model on the levels of variables. The downside is the loss in efficiency and power since it intentionally over-fit the VAR model. Wolde-Rufael (2006) uses this approach to examine 17 African countries. The growth hypothesis is confirmed in Ghana, Zimbabwe, Senegal, Cameroon, Zambia, and Nigeria. The conservation hypothesis is valid in Tunisia, Benin, and the Republic of Congo. The feedback hypothesis holds in Gabon, Egypt, and Morocco. The bound testing approach is also used by Kayikci and Bildirici (2015) to investigate the association between electricity consumption, economic growth, and oil rent for the MENA and GCC regions. They conclude that the causality between oil rent and economic growth with electricity usage depends on the abundant levels of natural resources. The Toda-Yamamoto approach can also be found in Squalli (2007), Altinay and Karagol (2005), and Tang (2008).

Besides four main generations of studies used in investigating the relationship between economic growth and electricity consumption, some notable papers used different methods. Das *et al.* (2012) examine 45 countries from 1971 to 2009 by employing the generalized method of moments (system GMMs) proposed by Blundell and Bond (1998) and find feedback effects. Likewise, Karanfil and Li (2015) examine 160 countries in the period of 1980-2012. They find that the relationship between two variables depends on regional differences, urbanization levels, income levels, and supply risk. Abdoli and Dastan (2015) study the relationship in OPEC countries by adding to the production function the export variable as a potential determinant. They use fully modified OLS (FMOLS) and note that trade and electricity usage stimulate economic growth and the presence of feedback effect in the short run. For GCC countries, Osman *et al.* (2016) use PMGE and demeaned AMG, DFE, PMG, and MGE approaches. They conclude that capitalization and electricity lead to economic advancement, and show that the feedback hypothesis is valid. However, they note that the direction of causality is from economic development to capitalization, and then capitalization to electricity consumption.

Most of the previous studies address the same question "Is there a causal relationship between the growth in national income and electricity usage, and if it exists, what is its direction?". In this paper, we only examine the unidirectional causality running from economic growth to electricity consumption. In other words, we directly test the conservation hypothesis at the macroeconomic level. By focusing on one direction of causality, we employ an instrumental variable approach to consistently estimate the effect of economic growth on electricity consumption. We believe that this study is the first empirical attempt. Thus, it contributes a different method and a different point of view to the voluminous literature on income and electricity usage.

3. Data and estimation strategy

3.1 Data

The exclusion restriction is that the variations of international oil prices only affect electricity consumption through GDP per capita. This could be violated if a country is the oil price maker or if a country uses oil to produce electricity. The solution to this problem is to use data from countries in which oil contributes to a low fraction of electricity produced with a normal threshold of 5% or data from the oil price-taking countries, which import or export a small proportion of world oil exports and imports, normally less than 3%.

With the two conditions mentioned above, we selected 32 countries and collected data from these countries from 1996 to 2014 because in the 1990s most of the countries stopped using oil as fuel to produce electricity due to the high cost of oil. Figure 1 shows the fraction of electricity produced by oil in selected countries from 1996 to 2014 (International Energy Agency, 2014). The annual data on international oil prices from 1996 to 2014 are from United Nations Conference on Trade and Development Commodity Statistics (UNCTAD, 2017).

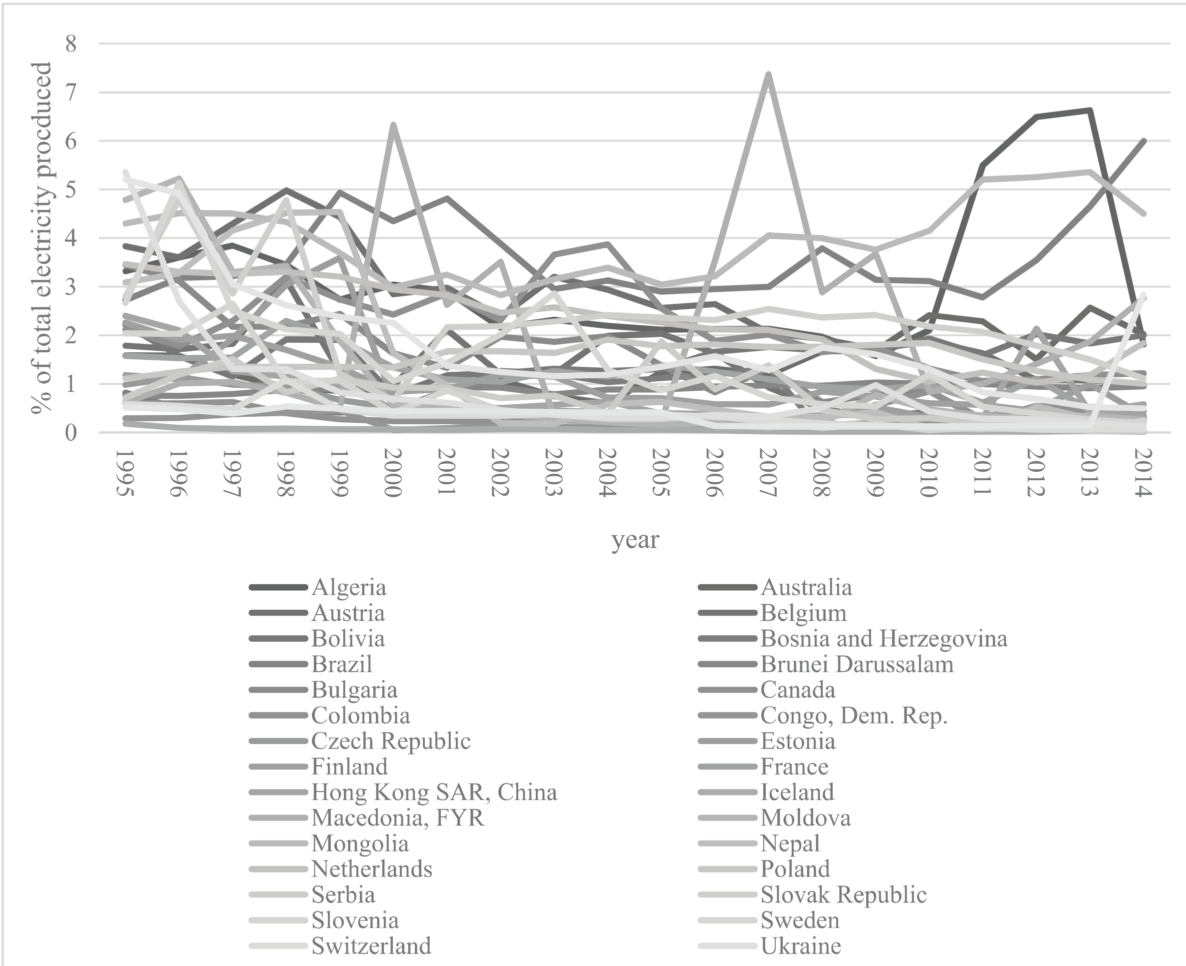

Figure 1. Electricity production from oil sources

Source: International Energy Agency (2014)

Figure 2 shows the variations of the oil price level from 1996 to 2014. The data on oil exports and oil imports from 1996 to 2000 are from NBER-United Nations Trade Database (Feenstra *et al.*, 2004). More recent data from 2001 to 2014 are from United Nations Comtrade Database (2017). The following data are drawn from World Bank (2018) online database: Electric power consumption (kWh per capita) is all year electricity consumption per person; GDP per capita is the gross domestic product in US dollar divided by midyear population; the annual savings rate is Gross savings divided by countries' GDP in that year and government expenditure is general government final consumption expenditure as a share of GDP. Total factor productivity is the annual growth rate in percentage, which is the portion of output not explained by inputs of labor and capital used in production, data is from The Conference Board Total Economy Database (2017).

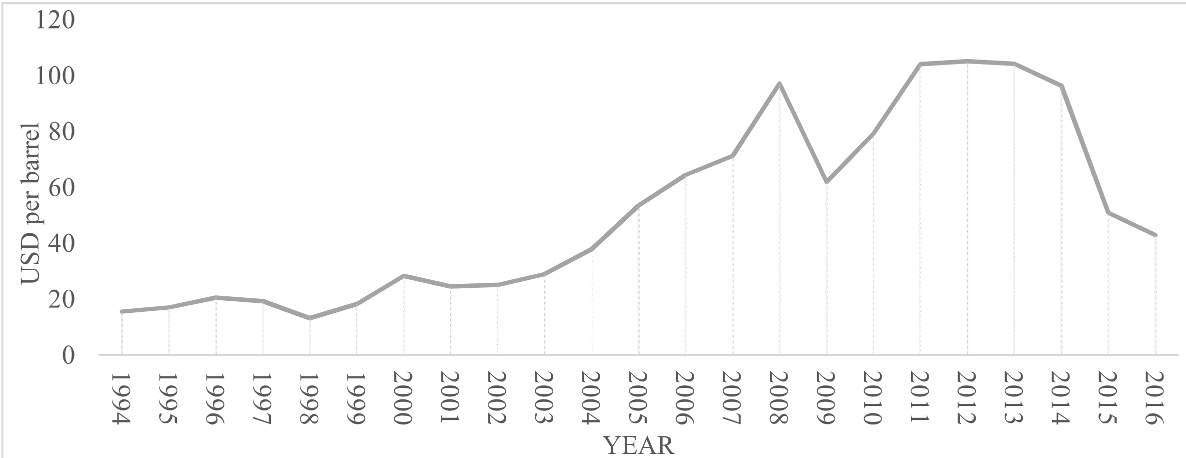

Figure 2. International oil price from 1994 to 2016

Source: UNCTAD (2017)

There are some limitations regarding the data used in this paper. The main focus of the study is the oil price shock variable, and the exclusion restriction to use oil price shock as an instrument for GDP per capita is that oil price only affects electricity consumption through the income channel. However, before the 1990s many countries have used oil as the main fuel to produce electricity. After the oil crisis in the 1990s, many countries have stopped using oil to produce electricity as the cost was too high and other alternatives became easier such as hydroelectric and nuclear power. Most countries have, however, slowly abandoned oil as a source to produce electricity, which makes electricity production from oil still account for a sizeable proportion in many following years. To avoid violating the exclusion restriction, we only choose countries that have less than 5% of the total electricity produced from oil sources. 32 countries satisfy this condition in a relatively short period between 1996 and 2014. As some countries' net oil export values almost equal to 0, which can make estimation less accurate due to collinearity, we retain only 600 observations.

3.2 Estimation strategy

3.2.1 Oil price shock instrument

The basic estimation equation explains the logarithm of the growth rate of countries' electricity consumption by the logarithm of the growth rate of GDP per capita as follows.

$$\Delta \ln(Elc_{it}) = m_i + n_t + \pi \Delta \ln(GDPp.c._{it}) + u_{it} \qquad (1)$$

where m_i is country fixed effects; n_t is year fixed effects, Elc_{it} is Electricity Consumption, GDPp.c. is GDP per capita.

The standard pooled OLS estimation equation is the same as Equation (1) without country and year fixed effect mi and nt, which is biased and inconsistent when $Cov(\Delta \ln GDPp.c._{it}, u_{it}) \neq 0$. This correlation is common in the literature of the relationship between national income and electricity consumption due to the possibility of underlying factors affecting both the potential for economic growth and the consumption of electricity. Endogeneity bias could exist due to changes in electricity consumption that affect national income. This reverse causality could be positive or negative. For example, more electricity consumption in the industrial field due to more machines being used can lead to more goods produced, which increase GDP. There is also the problem of omitted time-variant variables that directly affect both national income and electricity consumption. For example, a technological innovation incorporated in machines increases productivity and also electricity consumption. Most of the theories in economics, sociology, and political science state that Cov(ΔlnGDPp.c.it, uit) ≥ 0. If the conditions for fixed effects estimation to be consistent are violated, the estimation results will be biased upward. Thus, the fixed effect results can be used as upper bounds for the estimation of the causal effect of economic growth on electricity consumption. Consistent with this, the results of IV regressions show smaller coefficients of GDP per capita than the fixed effects results.

The oil price shock instrumental variable for country i in year t is built as in Equation (2) as follows.

$$OilPriceShock_{i,t} = \theta_i \Delta lnOilPrice_t \quad (2)$$

where θ_i is the average of net oil export relative to GDP of country i from 1996 to 2014; $\Delta lnOilPrice_t$ is the difference between the logarithm of international oil price at year t and t-1.

To investigate whether oil price shock affects electricity consumption through GDP per capita growth, the following estimation equation is used.

$$\Delta ln(Elc_{it}) = \alpha_i + \beta_t + \delta \Delta ln(GDPp.c._{it}) + \varepsilon_{it} \quad (3)$$

where α_i is country fixed effects; β_t is year fixed effects; ε_{it} is an error term; and GDP per capita is predicted by oil price shock variable. Coefficient δ, therefore, captures the causal effect of national income on electricity consumption. The estimation method is two-stage least squares. The identification restriction is that oil price shocks affect electricity consumption only through GDP per capita.

3.2.2 Saving rate instrument

The estimation equation is identical to Equation (3) except that the saving rate is used to instrument for Δln(GDPp.c.it).

$$\Delta ln(Elc_{it}) = a_i + b_t + \gamma \Delta ln(GDPp.c._{it}) + e_{it} \quad (4)$$

where a_i is country fixed effects; b_t is year fixed effects; e_{it} is an error term; γ is the main coefficient of interest. The estimation method is two-stage least squares. The identification restriction is that the saving rate does not directly affect electricity consumption.

4. Main results

4.1 Oil price shock instrument

The analysis is firstly conducted by estimating the effect of GDP per capita growth on electricity consumption. Panel A and Panel B of Table 1 show the estimation using the least square and the two-stage least square, respectively. In panel A, when controlled for time and country fixed effects, only the year t coefficient of 0.026 with a standard error of 0.014 is significant at the 10% significance level. The year t-1 coefficient of 0.033 with a standard error of 0.014 is significant at the 5 percent significance level. The further lags' coefficients are quantitatively small and insignificant. Coefficients at t and t-1 summed up to yield a cumulative effect of 0.065 with a standard error of 0.023. With a p-value of 0.005, this effect is significant at the 1% significance level. These findings indicate that national income has a positive effect on electricity usage that accumulates over time. Therefore, it is sensible to use the logarithm of the growth rate of GDP per capita over two years at t and t-1 as the main regressor. The oil price shock instrumental variable is then calculated as the logarithm of the growth rate of the international oil price from year t-1 to year t, which is weighted with the average proportion of oil net export in GDP of each country in the period of 1996-2014.

Column 1 of Panel A shows the standard pooled OLS regression without year or country-fixed effects. The coefficient of changes in the logarithm of GDP per capita is significant, confirming the common positive correlation between economic growth and electricity consumption in the literature. Although the effect of GDP per capita on electricity consumption in this estimation is significant at the 1% significance level, it is quantitatively small. The coefficient of two years' average GDP per capita growth is 0.033 with a standard error of 0.009, which means that a 10% increase in GDP per capita leads to a rise of 0.3% in electricity consumption, which is very small and unrealistic. We then add year-fixed effects in Column 2, and they are jointly significant at the 1% significance level. This implies that the estimates are affected by global trends. In Column 3, we replace year-fixed effects with country-fixed effects. Column 4 presents the basic results with both country and fixed effect. The results show that the relationship between national income and electricity consumption remains unchanged after controlling for country and year fixed effects. Similar to the pooled OLS estimation, the coefficient of GDP per capita growth in fixed effect estimation is significant at the 1% significance level, but still quantitatively small.

Panel B presents the results of the two-stage least squares estimation, in which GDP per capita growth is predicted by the oil price shock instrumental variable. The first-stage results show a strong connection between GDP per capita and the instrumental variable, with an F-statistic of 24.16. Both variables GDP per capita growth and oil price shock are calculated as the change in log. The oil price shock variable is weighted with the average proportion of oil net export in the GDP of each country in the period surveyed. Therefore, it is time-invariant. The estimates show that changes in the international oil price have a permanent effect on GDP per capita, which is also confirmed by Brückner *et al.* (2012) and Hamilton (2009). Without fixed effects, the coefficient becomes insignificant due to a larger standard error compared to the least square estimation. When country and year fixed effects are introduced, the coefficient remains insignificant but has a negative sign of -0.088 with a standard error of 0.065. That might be because variations in electricity consumption could lead to changes in GDP per capita growth. In this case, least-squares coefficients are much bigger than two-stage least squares coefficients due to the reverse causality, which supports the growth hypothesis. Another factor that can lead to this result is omitted variables that are time-variant and directly affect both GDP per capita growth and electricity consumption. If the omitted variable is the only source of endogeneity, the neutrality hypothesis is valid.

Table 1. Effect of income growth on electricity consumption

	Electricity consumption year t			
	Panel A: LS			
	(1)	**(2)**	**(3)**	**(4)**
GDP p.c. growth year t	0.060*** (0.013)	0.029*** (0.014)	0.054** (0.012)	0.026* (0.014)
GDP p.c. growth year t-1	0.009 (0.013)	0.035** (0.014)	0.002 (0.013)	0.033** (0.014)
GDP p.c. growth year t-2	0.012 (0.013)	0.009 (0.014)	0.004 (0.014)	0.006 (0.014)
GDP p.c. growth (2-year average)	0.033*** (0.009)	0.035*** (0.011)	0.028*** (0.009)	0.033*** (0.012)
	Panel B: 2SLS			
GDP p.c. growth (2-year average)	0.026 (0.062)	-0.088 (0.063)	-0.064 (0.055)	-0.088 (0.065)
	First-stage			
Oil price shock (2-year average)	1.494*** (0.399)	1.399*** (0.326)	1.962*** (0.459)	1.618*** 0.352)
Kleibergen Paap F-stat	14.03	18.45	18.25	24.16
Time FE	No	Yes	No	Yes
Country FE	No	No	Yes	Yes
Observation	608	608	608	608

Notes: The method of estimation in Panel A is least squares; Panel B is two-stage least squares. The dependent variable is total electricity consumption. The instrumental variable in Panel B is the change in the international oil price between year t and t-2 multiplied by the countries' average GDP share of net oil exports. Huber robust standard errors (shown in parentheses) are clustered at the country level. *Significantly different from zero at 10 significance, ** 5 percent significance, *** 1 percent significance.

Source: Author's calculation

Table 2 shows the results of the reduced form estimations of oil price shock on electricity consumption. The results are consistent with the results from Table 1. All of the coefficients are insignificant, even when controlled for country and year fixed effect.

Table 2. Oil price shock and electricity consumption

	Electricity consumption year t			
	(1)	**(2)**	**(3)**	**(4)**
Oil price shock year t	0.003 (0.133)	-0.161 (0.124)	-0.153 (0.132)	-0.020 (0.130)
Oil price shock year t-1	0.088 (0.133)	-0.007 (0.126)	-0.066 (0.134)	-0.048 (0.128)
Oil price shock (2-year average)	0.039 (0.094)	-0.093 (0.092)	-0.125 (0.100)	-0.142 (0.096)
Time FE	No	Yes	No	Yes
Country FE	No	No	Yes	Yes
Observation	608	608	608	608

Notes: The method of estimation is least squares. The dependent variable is total electricity consumption. Huber robust standard errors (shown in parentheses) are clustered at the country level. *Significantly different from zero at 10 significance, ** 5 percent significance, *** 1 percent significance.

Source: Author's calculation

Table 3. Excluded countries with low oil price shock value

	Electricity consumption year t			
	Panel A: LS			
	(1)	**(2)**	**(3)**	**(4)**
GDP p.c. growth (2-year average)	0.026 (0.060)	-0.090 (0.064)	-0.064 (0.055)	-0.091 (0.065)
	First-stage			
Oil price shock (2-year average)	1.496*** (0.412)	1.358*** (0.337)	1.963*** (0.475)	1.594*** 0.367)
Kleibergen Paap F-stat	13.18	18.15	17.05	19.53
Time FE	No	Yes	No	Yes
Country FE	No	No	Yes	Yes
Observation	468	468	468	468

Notes: The method of estimation is two-stage least squares. The dependent variable is total electricity consumption. The instrumental variable is the change in the international oil price between year t and t-2 multiplied by countries' average GDP share of net oil exports. Huber robust standard errors (shown in parentheses) are clustered at the country level. *Significantly different from zero at 10 significance, ** 5 percent significance, *** 1 percent significance.

Source: Author's calculation

In Table 3, we excluded some countries that have small θi values. Those countries have similar oil export and import value, making the net export value of oil really small. Since θi equals net oil export value divided by GDP, it will become close to zero and make those observations less meaningful due to collinearity. The excluded countries are Estonia, Hong Kong, Moldova, Nepal, and Slovenia. However, the results are similar to the previous estimations. The first stage remains fairly strong and there is no significant coefficient in the effect of GDP per capita growth on electricity consumption.

We also examine the effect of GDP growth on electricity consumption exclusively in European countries compare to other countries. The reason behind this is European countries have a higher level of development compared to others. They have different speeds of increase in electricity consumption and GDP per capita growth rate. Moreover, European countries use more renewable energy resources. Again, the main finding in Table 4 is the coefficients on GDP per capita in the European countries sample and other countries are insignificant.

Table 4. Are European countries different?

	Electricity consumption year t	
	Non-European countries	**European countries**
GDP p.c. growth	0.026	-0.090
(2-year average)	(0.060)	(0.064)
	First-stage	
Oil price shock	1.496***	1.358***
(2-year average)	(0.412)	(0.337)
Kleibergen Paap F-stat	13.18	18.15
Time FE	No	Yes
Country FE	No	No
Observation	468	468

Notes: The method of estimation is two-stage least squares. The dependent variable is total electricity consumption. The instrumental variable is the change in the international oil price between year t and t-2 multiplied by countries' average GDP share of net oil exports. Huber robust standard errors (shown in parentheses) are clustered at the country level. *Significantly different from zero at 10 significance, ** 5 percent significance, *** 1 percent significance.

Source: Author's calculation

Table 5 shows an overidentifying restriction test that the instrumental variable affects electricity consumption only through national income. Lagged GDP per capita levels are used as an additional instrumental variable for GDP per capita growth (2 years average). The lagged GDP per capita level is a valid instrumental variable if it only affects electricity consumption through GDP per capita growth. The idea of using lagged GDP per capita level as an additional instrument is from Brückner *et al.* (2012). From Table 5, we can see that the joint F statistic in the first-stage estimation when both oil price shocks (2 years average) and lagged GDP per capita levels are included as instrumental variables for GDP per capita growth is 14.19, which by the rule of thumb suggests that weak instruments problem is not present. The p-values of the Hansen test of overidentifying is 0.54, which means the Hansen test rejects the hypothesis of invalid overidentifying restriction. The table also presents the results when oil price shocks are used as an exogenous regressor conditioned on GDP per capita growth predicted by lagged GDP per capita levels. Again, the F statistic for the first stage when lagged GDP per capita levels is used to instrument for GDP per capita growth is quite strong at 11.34. The result shows that the (direct) effect of oil price shocks and GDP per capita growth conditioned on oil price shocks on electricity consumption are statistically insignificant. This confirms the exclusion restriction when using oil price shocks as an instrumental variable is not violated.

Table 5. Test of exclusion restriction I

	Electricity consumption year t	
	IV is oil price shock and lagged GDP per capita	**IV is lagged GDP per capita**
GDP p.c. growth	-0.037	0.116
(2-year average)	(0.053)	(0.106)
Oil price shock		-0.330
(2-year average)		(0.243)
Hansen J, p-value	0.54	
Kleibergen Paap F-stat	14.19	11.34
Time FE	Yes	Yes
Country FE	Yes	Yes
Observation	576	576

Notes: The method of estimation is two-stage least squares. The dependent variable is total electricity consumption. The instrumental variable is the change in the international oil price between year t and t-2 multiplied with countries' average GDP share of net oil exports and lagged GDP per capita level. Huber robust standard errors (shown in parentheses) are clustered at the country level. *Significantly different from zero at 10 significance, ** 5 percent significance, *** 1 percent significance.

Source: Author's calculation

The most important identifying assumption in our instrumental variables estimation is that changes in the international oil prices only affect electricity consumption through GDP per capita. However, there are other possible channels through which international oil price shock can affect electricity consumption. There are two possible channels, which are added to the regression models to see if the results still hold. The estimations results are presented in Table 6.

The first channel is the government. Variations in international oil prices can change the evaluation of countries' leaders about the future status of the world, thus affecting economic planning and making the government issue policies that may decrease electricity consumption like energy conservation policies, or increase electricity usage by pushing production. The relationship between government expenditures and oil price shock has been confirmed by Eltony and Al-Awadi (2001). Therefore, in Column 1 of Table 6, government expenditure is added as an additional exogenous variable. The results indicate that while the coefficient of government expenditure of 0.078 is significant at a 10 percent significance level with a standard error of 0.041, the coefficient of GDP per capita of -0.1 is still insignificant at a standard error of 0.068. F-statistic of 25.93 shows a strong first-stage relationship between oil price shock and GDP per capita. These results are consistent with previous findings and show no evidence of the causal effect of national income on electricity growth when controlled with government expenditures.

Table 6. Test of exclusion restriction II

	Electricity consumption year t		
	(1)	**(2)**	**(3)**
GDP p.c. growth (2-year average)	-0.100 (0.068)	-0.049 (0.102)	-0.051 (0.109)
Government expenditure	0.078* (0.041)		0.054 (0.079)
Total factor productivity		0.004*** (0.001)	0.004*** (0.001)
		First-stage	
Oil price shock (2-year average)	1.528*** (0.300)	1.586*** (0.588)	1.426*** (0.452)
Government expenditure	0.587*** (0.045)		0.706*** (0.043)
Total factor productivity		0.008*** (0.003)	0.006*** (0.002)
Kleibergen Paap F-stat	25.93	9.26	9.95
Time FE	Yes	Yes	Yes
Country FE	Yes	Yes	Yes
Observation	556	556	556

Notes: The method of estimation is two-stage least squares. The dependent variable is total electricity consumption. The instrumental variable is the change in the international oil price between year t and t-2 multiplied with countries' average GDP share of net oil exports, and in Column 1 has government expenditure, Column 2 has total factor productivity, Column 3 has both government expenditure and total factor productivity as an additional instrument. Huber robust standard errors (shown in parentheses) are clustered at the country level. *Significantly different from zero at 10 significance, ** 5 percent significance, *** 1 percent significance.

Source: Author's calculation

The second channel is technological progress. The relationship between oil price shock and technological progress has been verified by many studies. According to Cheon and

Johannes (2012), technological progress definitely will affect electricity consumption, either by more electrical devices produced or advance in power efficiency. In Column 2, total factor productivity is used to measure technological progress. The effect of total factor productivity is significant at the 1 percent significance level with a coefficient of 0.004 and standard error of 0.001. The coefficient of GDP per capita of -0.049 is still insignificant with a standard error of 0.102, showing no evidence of the causal effect of GDP per capita growth on electricity consumption.

In Column 3, both government expenditure and total factor productivity are added as additional regressors. F-statistic of 9.97 indicates that oil price shock still has an acceptable first-stage relationship with GDP per capita. The effect of GDP per capita on national income remains insignificant with a coefficient of -0.051 and a standard error of 0.109. Overall, the results in all cases are consistent with previous findings that there is no evidence of causality runs from GDP per capita to electricity consumption.

4.2 Saving rate instrument

The second instrument is the past saving rate. The identification restriction is that the saving rate does not directly affect electricity consumption. It is sensible to think that the saving rate will have an effect on income in the future, but does it affect electricity consumption? There is no precise theory that proves saving rate does not directly impact electricity consumption, but it seems reasonable that the saving rate in the past three years should not affect electricity consumption today other than through the income channel. Nevertheless, the saving rate can affect electricity consumption through some other channels. First, the saving rate could be affected by the government, which may issue policies that reduce or increase electricity consumption. Second, electricity consumption might be driven by the distribution of income or market structure that results in different savings rates. However, it will be shown that those are unlikely to be important concerns in the estimations.

Table 7 examines the effect of GDP per capita on electricity consumption in IV regression using past saving rates as an instrument. The saving rate is defined as the percentage of gross saving compared to GDP. The first column shows the standard two-stage least squares regressions in which the instrumental variable is the saving rate. With a t-statistic of 3.21 and an F-statistic of 10.28, the first-stage relationship between national income and the saving rate is acceptable. The two-stage least squares estimate the coefficient of the effect of GDP per capita on electricity consumption is 0.116 with a standard error of 0.164, which shows no causal effect running from national income to electricity consumption. The other two columns test the plausibility of the exclusion restriction and the robustness of the previous findings. Column 2 adds government expenditure as an additional explanatory variable to check if the association between government expenditure and the saving rate is responsible for results in Column 1. The first-stage coefficient of government expenditure is insignificant, and the two-stage least squares estimate is similar to the estimate without government expenditure, showing no causal effect of income on electricity consumption. Finally, Column 3 adds one more lag of the saving rate as an additional instrument. Adding further lag of saving rate will perform an overidentifying restriction test. In other words, whether the saving rate at year t-3 is a valid instrument is conditional on the saving rate at year t-2 being a valid instrument (Acemoglu *et al.*, 2008). The two-stage least squares coefficient of GDP per capita is again insignificant at the value of 0.105 with a standard error of 0.123, and the overidentification restriction test indicates that the instruments are valid.

Table 7. Two-stage least squares with savings rate instrument

	Electricity consumption year t		
	(1)	**(2)**	**(3)**
GDP p.c. growth year t-1	0.116 (0.164)	0.117 (0.156)	0.135 (0.138)
Government expenditure year t-1		0.063 (0.405)	
		First-stage	
Savings rate year t-2	0.003*** (0.0009)	0.003*** (0.0009)	0.0028** (0.0013)
Savings rate year t-3			0.001 (0.0014)
Government expenditure year t-1		-0.504 (0.765)	
Kleibergen Paap F-stat	10.28	10.05	6.26
Time FE	Yes	Yes	Yes
Country FE	Yes	Yes	Yes
Observation	455	455	455

Notes: The method of estimation is two-stage least squares. The dependent variable is total electricity consumption. The instrumental variable is the past savings rate level. Huber robust standard errors (shown in parentheses) are clustered at the country level. Columns 1 and 2 are fixed effect OLS regression, Column 3 includes savings rate year t-3 as an additional instrument. *Significantly different from zero at 10 significance, ** 5 percent significance, *** 1 percent significance.

Source: Author's calculation

Similar to the oil price shock instrument, lagged GDP per capita levels as an additional instrument for GDP per capita growth are added to test for exclusion restriction in Table 8. When both past saving rate and lagged GDP levels are used as instrumental variables, the joint F-statistic in the first-stage estimate is 15.60, which indicates a strong instrument. Also, the p-value Hansen test is 0.37, which means it rejects the hypothesis of invalid overidentifying restriction. Meanwhile, when lagged GDP per capita levels are added as the only instrument for GDP per capita growth, the F-statistic is 13.54, which indicates that the weak instrument is not the main concern. The direct effect of past savings rate on electricity consumption is insignificant at the value of -0.0001 with a standard error of 0.0007. Both cases show an insignificant coefficient of GDP per capita growth year t-1 on electricity consumption year t.

Table 8. Test of exclusion restriction III

	Electricity consumption year t	
	IV is past savings rate and lagged GDP per capita	**IV is lagged GDP per capita**
GDP p.c. growth year t-1	-0.068 (0.121)	0.105 (0.123)
Savings rate year t-2		-0.0001 (0.0007)
Hansen J, p-value	0.37	
Kleibergen Paap F-stat	15.60	13.54
Time FE	Yes	Yes
Country FE	Yes	Yes
Observation	576	576

Notes: The method of estimation is two-stage least squares. The dependent variable is total electricity consumption. The instrumental variable is the change in the international oil price between year t and t-2 multiplied with countries' average GDP share of net oil exports and lagged GDP per capita level. Huber robust standard errors (shown in parentheses) are clustered at the country level. *Significantly different from zero at 10 significance, ** 5 percent significance, *** 1 percent significance.

Source: Author's calculation

Overall, the two instrumental variables strategies give consistent results that show no causal effect running from income to electricity consumption. However, this does not mean electricity consumption does not affect income. The results only indicate that there is no unidirectional causality running from national income to electricity usage, which means the conservation hypothesis and feedback hypothesis do not hold, leave us with growth hypothesis and neutrality hypothesis. As mentioned before, endogeneity can arise due to reserve causality. In this case, electricity positively affects GDP per capita growth. If this is true, the growth hypothesis is also true. In this case, electricity conservation policies should not be implemented as it will badly affect economic growth. Instead, governments should produce more electricity to meet the demands and focus on increasing electricity efficiency rather than reducing electricity usage. Endogeneity can also exist due to omitted variables, that affect both electricity usage and income. This is the case of the neutrality hypothesis, and in this case, electricity conservation policies can be implemented to reduce pressure on the environment.

5. Conclusion

In this paper, the results indicate that although income and electricity consumption are positively correlated, there is no evidence of the causal effect of economic growth on electricity consumption. One reason for this positive correlation is electricity consumption may have a direct impact on economic growth. Another reason is that there could be other factors that affect electricity consumption beyond GDP per capita growth, for example, technological progress. To the best of our knowledge, this paper presents the first empirical attempt to use the instrumental variables approach to estimate the causal effects that growth in GDP per capita has on electricity consumption. Panel data of 32 countries from 1996 to 2014 are used. An instrument for GDP per capita as the logarithm of the growth rate of the international oil price-weighted with the average proportion of oil net export in GDP of each country in the period of 1996-2014 is applied. Past savings rates as a second instrument are also tested. Controlling for country and time fixed effects helps to deal with time-invariant variables related to countries' history, industry structure, and the human aspect that could affect both national income growth and electricity consumption, and world business-cycle effects respectively.

When controlled for country and year fixed effects and employed instrumental variables, the regressions show no evidence of a causal effect of national income on electricity since the 1990s. Future studies should resolve the remaining concerns in this paper. First, while the results do not show evidence for a causal effect of GDP per capita growth on electricity consumption, such an effect can still exist at a much higher lag, for example, for more than 10 years. If more data are available in the future, this theory can be tested when countries completely stop using oil to produce electricity. Second, this causal effect might be caused by other time-variant characteristics that cannot be found using the available cross-country data. Finally, the results do not indicate that electricity consumption does not affect economic growth. Knowing whether electricity consumption affects economic growth will greatly help governments to imply suitable policies, but another methodology is needed to answer this question.

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