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The Impact of Clean Energy on Economic Growth:

An Econometrics Approach

Cheng Zhang

Introduction

For the past five decades, environmental issues have attracted increasing attention throughout the world. This is illustrated by events such as the United Nations Meeting on Humans and the Environment, held in Stockholm, Sweden in 1972 resulting in the U.N. Declaration on Human and Environment; in 1992, the U.N. Conference on Environment and Development, held in Rio de Janeiro, generated the Earth Charter; in 1995, the U.N. Framework Convention on Climate Change regulated U.N. Climate Change Conference once a year, and paved the way for Kyoto Protocol; in 2009, the U.N. climate change conference in Copenhagen was known as “the last chance to save the world;” and in 2012, COP17 at Doha, Qatar discussed the second phase of the Kyoto Protocol.¹

Though these events have demonstrated major concerns, the world has seldom taken action. The global economy now is heavily dependent on energy generated by fossil fuel consumption to meet basic needs. As the world’s population grows, fossil energy consumption is projected to increase by 50 percent.² The US Department of Energy

¹ Joe Smith. Copenhagen is the last chance to save the world. (2009). Available: <http://www.open.edu/openlearn/nature-environment/the-environment/environmental-studies/copenhagen-the-last-chance-save-the-world-ldquo-again>. Last accessed 8th April 2013.

² Eric McLamb. Fossil Fuels vs. Renewable Energy Resources. (2011). Available: <http://www.ecology.com/2011/09/06/fossil-fuels-vs-renewable-energy-resources/>. Last accessed 8th April 2013.

predicted that the world's available fossil fuel reserves will be depleted early in the 22nd century.³

In the meantime, many countries have expressed worry that developing clean energy technology will hinder economic growth. This is because most of these technologies are still in their infancy. These new technologies for energy production are far from practicable and there is a potential risk of a production cost surge. For example, the United States signed the Kyoto Protocol in 1998 but President Clinton did not ask the Congress to ratify it due to its potential cost. Citing further concerns, Canada also announced it would exit the Kyoto Protocol at the end of 2011⁴.

Indeed, the relationship between clean energy and economic growth has long been a topic of intense debate. Theoretical analysis began with Dr. Simon Kuznets, 1971 winner of the Nobel Economics Prize, who proposed the Environmental Kuznets Curve (EKC) hypothesis. Dr. Kuznets argued that the relationship between the environment and economic growth can be expressed in the shape of an inverted-U: environmental quality deteriorates with economic growth in the first stage, and improves after a turning point in which the economy reaches a relatively more productive level.

Studies on the relationship between the environment and economic growth vary in methodology and conclusion: some research focuses on greenhouse gas emission, some relies on water pollution indicators, and others pay attention to deforestation or urban waste generation. These different areas of analysis indicate that the proper approach to this topic

³ EIA. FOSSIL. (2012). Available: <http://energy.gov/science-innovation/energy-sources/fossil>. Last accessed 8th April 2013.

⁴ Austen, I. (2011, December 12). Canada Announces Exit From Kyoto Climate Treaty. The New York Times. Retrieved , from http://www.nytimes.com/2011/12/13/science/earth/canada-leaving-kyoto-protocol-on-climate-change.html?_r=0

should be multi-faceted. This paper collects data about economic performance and clean energy from 1961 to 2011 in 214 countries and regions, and aims to answer whether clean energy adoption and carbon dioxide emission deduction would delay economic development.

Literature Review

Some researchers have focused their study on individual countries, attempting to discover the relationship between the environment and economic growth, and provide possible solutions for individual countries. J. R. Vincent et al (1997) used the case of Malaysia to study the interaction among natural resources, environmental policies, and economic development. Meanwhile, G. Atkinson et al (1997) began a similar study from a macroeconomic perspective: they employed empirical measurement of sustainable development, resource and environmental accounting, international trade, ecological indicators, income distribution, and the adjustment policies, aimed at determining whether an economy is on a sustainable development path.

Sun (1999) analyzed the EKC based on a study of France, Germany, Japan, UK, and US. The study found that the EKC summit for the US was the 1880s; for the UK and Germany was the 1920s; for France was 1929; and for Japan was the 1970s. Similarly, Roca and Alcantara (2001) conducted a study based on data from Spain. They conducted a time series analysis, but concluded that there was no decrease in Spain's carbon dioxide (CO₂) emissions in the past two and a half decades.

Friedl and Getzner (2003) introduced a cubic specification in the regression model to study the case in Austria. They found a rapid increase of CO₂ emissions along with GDP

growth, and concluded that an effective way to reduce CO₂ emissions is to introduce a carbon tax.

Kojo and Yemane (2010) studied the long-run causal relationships between economic growth, pollutant emissions and energy consumption in South Africa. They concluded that South Africa has to sacrifice economic growth or reduce its energy consumption for a better environment, but in the long run, it is possible for them to “meet the energy needs of the country and at the same time reduce CO₂ emissions by developing alternatives energy.”⁵

Meanwhile, other researchers analyzed this topic among several countries, and most of these confirmed the possibility that economic growth may be achieved while developing clean energy projects. In 1996, there were nearly two billion people that were without electricity, and at the same time a similar number remained dependent on fuels such as animal dung. The uneven distribution and low efficiency of energy had become a major issue that challenges the world’s economy. Douglas F. Barnes and Willem M. Floor (1996) of the World Bank suggested that the marketization of energy was a good solution. However, marketization meant an increased demand of energy, which greatly damaged the environment in some resource-rich countries.

Moomaw and Unruh (1997) analyzed CO₂ intensity and GDP within 16 OECD member countries. The result of the analysis testified that the EKC has positive impact upon GDP in per capita and cubed model. The fixed effect regressions performed especially well compared with OLS regression models. All estimations are statistically significant in the

⁵ Kojo Menyah, Yemane Wolde-Rufael. Energy consumption, pollutant emissions and economic growth in South Africa. *Energy Economics*. (2010).

cubic EKC model. The 0.04×10^{-11} coefficient of CO_2 suggests that every one unit increase in CO_2 leads to 0.04×10^{-11} increase in GDP according to the regression.⁶ But, much of the ‘inverted U-shaped relation’ effect and the presence of the third-order polynomial may be attributable to polynomial curve fitting rather than to underlying structural relationships.

Roberts and Grimes in 1997 used a logarithmic specification of CO_2 intensity and GDP within 147 countries. Based on their per capita incomes, the authors divided these 147 countries into three categories: low-income, mid-income, and high-income. The results suggested that efficiency improvement occurred in high-income countries, but was not present in low- or mid-income countries. They supposed that “high-income countries moving their high-pollution industries to developing countries” is a possible explanation.

Schmalensee et al. in 1998 used data from 141 countries to test the EKC, and found that the CO_2 emissions deduction showed up in some countries as per capita income increased. With the help of tradable permissions, the participants in the market may exchange them in the Emissions Exchange market. As a result, the tradable permit program both produce surprises and adapt reasonably efficiently to surprises produced elsewhere in the economy, and the economic achieved expansion under the deduction of emission.⁷

Professor Daniel M. Kammen (2001) analyzed renewable energies (mainly biomass energy), sustainable development, and poverty in developing countries, and claimed that with renewable energies, the nation can achieve economic growth and emission reduction at the same time.

⁶ WILLIAM, M., & UNRUH, G. C. Are environmental Kuznets curves misleading us? The case of CO_2 emissions . *Environment and Development Economics*, 2, 451. (1997).

⁷ Schmalensee, R., Joskow, P. L., Ellerman, A. D., Montero, J. P., & Bailey, E. M. (1998). An interim evaluation of sulfur dioxide emissions trading. *Journal of Economic Perspectives*, 12, 53-68.

Professor Kent E. Portney (2003), from Tufts University, studied sustainable development in 24 cities in the U.S., and introduced the “taking sustainable cities seriously index” as an indicator for economic development. The research employed quantitative analysis of data from 24 United States cities, focusing on the process of development, rather than the results.

In 2011, Yongfu Huang and Terry Barker studied the link between Clean Development Mechanism (CDM) projects and CO₂ emissions per capita for 80 countries from 1993 to 2009. They found a decline in CO₂ emissions associated with CDM projects, and encouraged “developing countries to effectively develop CDM projects towards low carbon development.”⁸

Data and Methodology

Our research collects data from 214 countries and areas that were observed by the World Bank. The time range is 50 years, covering the period 1961 to 2011. Gross Domestic Product (GDP) Per Capita Growth is used as the dependent variable, and the main independent variable is the percentage of clean energy in total energy consumption. The research uses carbon dioxide emission and signature of Kyoto Protocol as instruments for the instrumented independent variable *alenergy*, and chose the real interest rate, energy consumption, the percentage of net export in GDP, patent authorized by the government, and average hourly wage as control variables.

With the time range of 50 years, and the category range of 214 countries and areas,

⁸ Yongfu Huang and Terry Barker. The Clean Development Mechanism and low carbon development: A panel data analysis. *Energy Economics*. (2012).

we chose a combined model of IV-Regression and two-way Fixed-Effect Regression. In this model, to avoid the bias from omitted factors that are constant across states but evolve over time, and the potential variables that are constant over time but vary across the states, the two-way Fixed-Effect model was adopted. Considering all other potential omitted variables that may bring omitted variable bias into the model, we also use instrumental variables.

The original dependent variable is GDP Per Capita Growth. It was collected as GDP per capita based on purchasing power parity from the World Bank Database. The GDP from different countries is converted to international dollars using purchasing power parity rates. To calculate the growth rate, the formula below is adopted:

$$\text{GDP Per Capita Growth} = \frac{\text{PPP GDP Per Capita}_2 - \text{PPP GDP Per Capita}_1}{\text{PPP GDP Per Capita}_1}$$

The independent variable *alenergy* is collected from World Bank. It calculates alternative energy consumption rate of all energy consumption, to evaluate the level a country has reached in the clean energy field. The World Bank alternative energy variable includes non-carbohydrate energy that does not produce CO₂ including solar, hydro, and wind.

The control variables of real interest rate, energy consumption, and net export are also collected from the World Bank. Patent authorization⁹ and average hourly wage come from the Organization for Economic Cooperation and Development (OECD) Database.

The format of the data are also changed so as to meet the requirements of the

⁹ Clean Energy industry is always considered as the high-tech industry that involves a huge amount of patents. Thus, the patent authorization variable is considered to suggest the level that technology development level, as well as the extent that government protect the R&D process within the country.

regression models: the distributions of energy per capita, carbon dioxide energy consumption per capita, and the percentage of clean energy are highly right skewed, with a long tail. Thus logarithmic forms of the data were adopted. Since the dataset is unbalanced and suffers from missing variables among observations, we use a subset of recent 10-year data with complete observations to test for stationarity. As a result, the delta form of *net export*, *wage*, and the logarithmic delta form ($\log(\Delta\text{patent})$) of *patent* are used, instead of the regular form to satisfy the stationary restriction. The detailed descriptive statistics and correlations on variables are listed in the following two tables:

Table 1 : Descriptive Statistics on Variables

Variable	Obs	Mean	Std. Dev.	Min	Max
GGPC	5106	0.046	0.064	-0.484	0.963
$\ln(\text{epc})$	5352	-6.673	1.089	-11.616	-3.769
$\ln(\text{gale})$	4535	0.986	1.920	-7.460	4.783
RI	4360	6.483	20.635	-97.812	789.799
$\Delta \text{netexport}$	7173	0.367	5.738	-65.055	59.192
<i>patent1</i>	1004	3.182	2.132	-2.996	8.861
Δwage	986	2.928	2.390	-7.863	19.359
$\ln(\text{GPC1980})$	6579	7.691	1.228	5.336	10.983
$\ln(\text{cepc})$	8471	-6.651	1.796	-14.401	-2.283
Signature	10914	0.101	0.302	0.000	0.000

Table 2 : Summary of Correlations on Variables

	GGPC	logepc	logale	RI	d.netexp ^{~t}	patent1	d.wage	log ^{~1980}	logcepc	signat ^{~e}
GGPC	1.000	-	-	-	-	-	-	-	-	-
Ln(epc)	-0.086	1.000	-	-	-	-	-	-	-	-
ln(ale)	-0.131	0.141	1.000	-	-	-	-	-	-	-
RI	-0.322	-0.017	-0.053	1.000	--	-	-	-	-	-
Δ netexp^{~t}	0.164	-0.017	-0.085	-0.090	1.000	-	-	-	-	-
patent1	-0.235	0.174	0.327	-0.025	-0.024	1.000	-	-	-	-
Δ wage	0.237	-0.262	0.059	-0.054	-0.003	-0.138	1.000	-	-	-
ln(GPCI1980)	-0.135	0.506	-0.039	0.173	-0.037	0.023	-0.435	1.000	-	-
ln(cepc)	0.013	0.712	-0.386	0.003	-0.032	0.105	-0.242	0.379	1.000	-
signature	-0.119	0.075	0.087	-0.381	-0.041	0.316	-0.012	-0.122	0.034	1.000

In order to assess the validity of the instruments, we will first confront issues of exogeneity.

For carbon dioxide emission, there are businesses such as contractors and manufacturers that receive limited revenue but produce immense emission; while there are also businesses existing within emerging industries that had little emission but achieve astonishing profits and ROIs by top techniques and patents. Thus our empirical experiences suggest there is no significant correlation between carbon dioxide emission and GDP per capita growth.

Analyses from recent decades confirm this. Douglas H. E. and Thomas M. S., 1995 examine the relationship between economic development and CO₂ emission, and conclude that “global carbon dioxide emissions growth ... is not sensitive to average output growth.”¹⁰ Also for the potential indirect impacts, Grubb, M., Bulter, L. and Feldman, O., from University of Cambridge, conducted an analysis in 2006, studying trends over time and economic growth rates, indicating that “there is not a unique relationship between emissions and income per capita that applies regardless of time and place.”¹¹

¹⁰ Douglas Holtz-Eakin, Thomas M. Seldena. *Stoking the fires? CO2 emissions and economic growth*. Journal of Public Economics. (1995). 57, p85-101.

¹¹ Grubb, M., Bulter, L. and Feldman, O... *Analysis of the Relationship between Growth in Carbon Dioxide Emissions and Growth in Income*. (2006) Available: <http://www.econ.cam.ac.uk/rstaff/grubb/publications/GA12.pdf>. Last accessed 8th April 2013.

Regarding our other instrument, *signature*, 93 countries have signed the protocol, and 191 countries ratified it¹². That means the signatories cover both developed countries and also developing countries, regardless of the scale of the economy.

Admittedly, there are arguments regarding the relationship between economic development and CO₂ emission. Some, as described above, believe there are positive relationships that higher CO₂ emission may suggest a better economic condition and faster development pace. But others insist that there is no statistically significant relationship for these two variables. To address this problem, we adopt two instruments to over identify the independent variable Ln (*ale*). The variables *ln(cepc)* and *signature* can be securely considered as exogenous in the IV-Regression. We also ran tests for endogeneity and instrument strength, to ensure that CO₂ emission and signature of Kyoto Protocol can be considered good instruments for independent variable *alenergy* in the Fixed-Effect-IV-Regression.

Therefore, the final regression specification is:

$$GGPC = \beta_0 RI + \beta_1 \logcepc_{it} + \beta_2 \Delta.netexport_{it} + \beta_3 \Delta.patent_{it} + \beta_3 \Delta.wage_{it} + \beta_4 \logale_{it} + \varepsilon_{it}$$

$$\logale = \gamma_0 + \gamma_1 \logcepc + \gamma_2 signature + u_{it}$$

Result Analysis and Interpretation

Table Three shows the key results of our regression models.

¹² UNFCCC. *Status of Ratification*. (2012). Available: http://unfccc.int/kyoto_protocol/status_of_ratification/items/2613.php. Last accessed 8th April 2013.

Table 3 :Multiple Regression Estimates of GDP Growth Per Capita (GGPC)				
	OLS	IV-Reg	XT-Reg	XT-IV-Reg
Ln(ale)	-0.002	-0.003	-0.013	-0.044
	-1.84	-0.002	(0.004)***	(0.014)***
Ln(epc)	-0.001	0.001	-0.044	-0.041
	-0.1	-0.006	-0.025	(0.019)**
RI	-0.003	-0.003	-0.003	-0.003
	(4.37)***	(0.001)***	(0.001)**	(0.001)***
Ln(GPC1980)	0.002	0.001		
	-0.28	-0.008		
Δ netexport	0.001	0.001	0.002	0.002
	-1.67	-0.001	-0.001	(0.001)***
patent1	-0.003	-0.003	-0.003	-0.002
	(3.81)***	(0.001)***	(0.001)**	-0.002
Δ wage	0.004	0.004	0.005	0.005
	(2.76)***	(0.001)***	(0.002)***	(0.001)***
_cons	0.051	0.077	-0.144	-0.074
	-0.54	-0.092	-0.137	-0.113
R2	0.21			
N	416	404	416	404
SER		0.03	0.02	.
R²	0.21	0.218	0.263	.
AdjustedR²		0.205	0.252	.
** p<0.05; *** p<0.01				

The first column shows the coefficient of alternative energy consumption percentage and GDP Growth Per Capita in an OLS regression model including all control variables. The coefficient of $\ln(ale)$ is -0.002. This indicates that there is a negative relationship between alternative energy consumption percentage and GDP Growth Per Capita, and that with every one percent increase in the alternative energy consumption ratio, the GDP Growth Per Capita decreases 0.002% points of growth per capita. This suggests that the increasing application of alternative energy will delay the economic growth a trivial amount for a certain country, but it is not statistically or economically significant in the regression model. There are other variables that may also affect GDP Growth Per Capita: the first is energy consumption per

capita with the coefficient of -0.002 , which means every one percent increase in energy consumption per capita may result in 0.00002 units decrease for the GDP Growth Per Capita. Another statistically significant variable is *real interest rate* with the coefficient of -0.003 . This means if the real interest rate increases one more unit, the GDP Growth Per Capita would decrease 0.003 . The third statistically significant variable is *patent*. The coefficient is -0.003 , and a one unit increase suggests 0.003 units decrease for the GDP Growth Per Capita. The fourth statistically significant variable, *wage*, with the coefficient of 0.004 , suggests that with a one unit change in hourly wages, the GDP Growth Per Capita would increase 0.004 . In this regression, the R-squared of 0.21 is relatively. This means that about 21% of the variance of GDP Growth Per Capita can be explained by the OLS regressors. There is a good case for continued omitted variable bias here.

The second column is the IV-Regression that is designed to eliminate the potential omitted variable bias. Two variables *ln(cepc)* and *signature* were chosen as the instruments, to predict the variable *ln(ale)*. The correlation test and zero-coefficient test suggest that the two variables have no correlation with the dependent variable *GGPC*, and are strongly related to the instrumented variable *ln(ale)*. Moreover, our empirical experiences and academic analyses suggest no causal relationship.

The result of the IV-Regression shows that it explains 20.5% of the variance in the dependent variable *GGPC*, which is incrementally lower than 21% in the first OLS regression. In this regression, most of the coefficients remain the same, with only two exceptions: *ln(ale)* and *ln(epc)*. The coefficient for *ln(ale)* changed from -0.002 to -0.003 , but is still not

statistically significant in the IV model. However, the coefficient for $\ln(epc)$ changed from -0.001 to 0.001. This change supports what we would expect: more energy consumption means faster economic growth. However, the coefficient is close to zero and is did not change considerably under this specification.

After reviewing the IV-Regression model, we decided to further control for omitted variables, including time and nationality, and chose to use regression specifications that integrate variation across time. We conducted a Hausman test in order to determine if a fixed-effects or random-effects regression is appropriate. The P value for Hausman test is near zero, indicating that we should adopt fixed-effect approach.

The third column demonstrates the result of fixed-Effect Regression. In this regression, the coefficient for $\ln(ale)$ changed from -0.003 to -0.013, showing that the variable $\ln(ale)$ has a much larger impact upon dependent variable $GGPC$. Meanwhile, this coefficient becomes statistically significant at the 1% level. The other variable coefficient that changed is the hourly wage ($\Delta wage$): it increases from 0.004 to 0.005, suggesting that in this new regression, with a one unit change in hourly wages, the GDP Growth Per Capita would increase 0.004, which is still statistically significant. In addition, the coefficients for real interest rate (RI) and patent (patent1) remain the same, but become only statistically significant at the 5% level. The adjusted R-squared value for this Fixed-Effect Regression is 0.263. It suggests that this regression can explain 26.3% of the variance in the dependent variable GDP Growth Per Capita.

In the fourth column, the specification adopted is a combined model of instrumental

variable and fixed-effect regression. This specification controls for time and nationality, and at the same time, contains the instrumented variable $\ln(ale)$.

The result for this new regression demonstrates that nearly all the coefficients changed: the coefficient for $\ln(ale)$ changed from -0.013 to -0.044, and become statistically significant at 1%. It indicates that every 1% increase in alternative energy consumption ratios will result in a 0.044% decrease in *GGPC*. This can be considered as a large impact upon economic growth because, for a developed country like the United States, the annual GDP Growth Per Capita remains lower than 3%, and a 20% increase in alternative energy consumption ratios will result in a 0.88% decrease. This, undoubtedly, will be a disaster for the country's economy. Thus we can conclude that using alternative energy would delay the economic growth. The reason for this negative relation may lie in the fact that alternative energy is not as efficient, meaning that developing alternative energy requires significant research and capital, but with a lower efficiency return for the high cost. Under these circumstances, the pace for promoting alternative energy programs becomes a consideration of vital importance.

Also, the $\ln(epc)$'s coefficient changed, from -0.044 to -0.041. This is not a significant change, but becomes statistically significant at the 5% level. The coefficient means a 1% increase in energy consumption per capita will result in a 0.00041 decrease in *GGPC*. The result does not match our expectations, because more emissions should mean more production, and should result in more GDP growth. An explanation for this negative relationship may be that for those industries that can drive GDP growth should be the

high-tech emerging industries and we would expect those high-tech industries to have lower emissions. Besides, with the coefficient for $\ln(epc)$ being significant at 95% level, the result may still suffer from bias from missing observations.

There are also other changes: the coefficient for net export remains the same as the former IV Regression, but it becomes statistically significant at the 1% level in the new regression; the coefficient for patent decreased 0.001, and became not statistically significant. This is because too many missing observations existed in the patent variable, and those missing observations lead to this insignificant coefficient.

Limitations

The first threat to our analysis is unbalanced panel data, due to missing observations. The data used in this paper was collected primarily from the Word Bank and OECD Databases. Though they cover a wide range of 214 countries and areas, and a time period from 1961 to 2011, the missing observations still hurt the accuracy of the analysis: some variables such as patent contain only a very small portion of data and other parts are left blank. And it is highly possible that the missed patent data results in the variable's statistical insignificance. Additionally, some countries and areas such as Aruba, Bermuda and Cuba suffered from missing observations. More accurate and sufficient data can greatly improve the quality of this analysis.

The second weakness for this analysis comes from the unbalanced data: when conducting the test for stationarity, the algorithm required strongly balanced data. But the dataset directly collected from Word Bank Database and OECD Database failed to fulfill this

requirement. The solution this paper adopted is to select a subset, with a much shorter time range: the time range for GGPC, RI, and Net Export is from 2002 to 2011; the time range for patent is from 1977 to 2011; the time range for wage is from 1984 to 2011. All the variables passed the test for stationarity based on these subsets. There is still a threat however that the variables within the full dataset may not pass this test for stationarity. Thus, a further test for stationarity is required for further analysis.

Conclusion and Recommendation

Based on our empirical work, we have reached two conclusions with policy implications. First, consuming energy is not the only solution to economic growth. Developing alternative energy will, according to our results, harm GDP growth. However, the influence can be controlled within a small range if we can promote the project step by step. Thus, policymakers should acknowledge that gradually developing alternative energy technology will not delay the economic development as much as expected. The initial stage of developing alternative energies might be painful, but if the efficiency of alternative energy can be improved, and if the scale can be increased, it would be easier to turn to alternative energy as a major energy source and economic development would not suffer greatly.

Second, more fossil fuel consumption to satiate energy needs does not always bolster economic growth, as demonstrated by the four regression models adopted in this paper. The negative relationship between GDP growth and energy consumption per capita suggests that simply increasing energy consumption will not absolutely lead to an increase in GDP growth due to energy-intensive yet low profit margin industries; rather, it may result in a decrease as

suggested by our models. Thus, developing alternative energy can be viewed as a long-term investment for the future of the country, and can benefit the economy by reducing traditional energy consumption.

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