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Modeling Renewable Energy Consumption for a Greener Global Economy

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1. Introduction

Climate change, resource depletion, and energy security are powerful forces helping to stimulate interest in renewable energy consumption. Renewable energy (defined broadly as energy generated from geothermal, wind, solar, tide and wave, wood, waste, and biomass) can help to address carbon dioxide related climate change, is not depletable, and is not susceptible to energy security issues the way that oil is. In response to these forces, it is widely expected that renewable energy will play an increasingly greater role in the overall share of energy consumed. This has helped to generate an increased interest into the relationship between renewable energy consumption and economic growth.

Climate change is now recognized as one of the biggest threats to society (Stern 2007, 2009). Climate changes such as rising temperatures, rising sea levels, acidification of the world's oceans, altered rain fall patterns, and greater variability in weather patterns, have the potential to seriously disrupt business activity. In particular, climate change can affect business activity through industry specific risks like regulatory and physical risks and company specific risks like reputation, litigation and competitive risks (Labatt & White, 2007). According to the World Resources Institute, 61.4% of global GHG emissions come from the energy sector[1] which means that any serious attempt to control greenhouse gas emissions will have to reduce fossil fuel consumption and increase renewable energy consumption. Effectively reducing fossil fuel consumption will require putting a price on carbon (either through taxes on carbon intensive products or a cap and trade emissions trading system) with the result that carbon based energy products like oil will increase in price. Pricing carbon will raise the price of carbon intensive energy products and help to encourage a substitution to low carbon energy sources.

Resource depletion and in particular, peak oil concerns stem from Hubbert (1956) who, in one of the scenarios he considered, forecast that US domestic oil production would peak in 1970. According to data provided by BP (2010), US domestic oil production did peak in 1970 at 11 million barrels of oil per day. Hubbert (1971) went on to predict that global oil production would peak in 2000. To date, global oil production has not yet peaked, but the general consensus is that it will soon (Verbruggen & Marchohi, 2010; Almeida & Silva, 2009). While there are lots of different authors predicting the year for peak global oil

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[1] http://cait.wri.org/figures.php?page=World-FlowChart&view=100

production, the consensus seems to be that peak oil will occur before 2015 (Almeida & Silva, 2009). If proponents of peak oil are correct and global oil production is soon going to peak, then what happens after the peak? The most likely scenario would be a lengthy adaptation phase during which energy efficiency is increased, short-term transitional energy sources are developed, and long-term sustainable energy sources are developed (Almeida & Silva, 2009). Peak oil brings higher oil prices and the revenues from higher oil prices can be used to support financing of renewable energy.

Energy security issues refer to the fact that many of the largest oil consuming countries are net oil importers and that much of the world's proven oil reserves are located in just a few countries. In 2009, four countries, Saudi Arabia, Iran, Iraq, and Kuwait accounted for 46.3% of the world's 1.333 trillion barrels of proven oil reserves (BP, 2010)[2] [3].In addition to having to pay a hefty bill for imported oil, this makes oil importing countries vulnerable to oil supply disruptions (oil embargos, terrorist attacks, political unrest) and oil price shocks. In 2009, the four largest oil consuming countries (US (21.7%), China (10.4%), Japan (5.1%), and India (3.8%)) were all oil net importers[4]. The United States imports approximately 66% of the oil that it consumes and in 2009, imported 3.25 billion barrels of oil (BP, 2010). At an average price of $61.92 per barrel for West Texas Intermediate crude oil, the total cost of US oil imports in 2009 was $201 billion dollars or $16.8 billion per month. Now suppose that at sometime in the near future, the US imports the same amount of oil, but the average price rises to $100 per barrel. In this case, the bill for oil imports would be $325 billion dollars or $27 billion per month. This is a lot of money to pay for imported oil, especially for a country that has a large trade deficit and an enormous federal budget deficit[5] [6]. Looking to the future, the 2009 US bill for imported oil is likely a minimum value because for the first six months of 2009 the US was in the worst economic downturn since the Great Depression of the 1930s. As the US economy recovers from the 2008-2009 recession oil demand and oil imports will surely rise.

As a result of these developments on climate change, resource depletion, and energy security it would be useful for policy makers to have an idea of how renewable energy consumption, income, oil consumption, and oil prices interact at the global level. The purpose of this paper is to develop and estimate a vector autoregression (VAR) model to investigate the dynamic interactions between these variables for the global economy. The model is used to analyze short-term dynamics and to make forecasts into the future until the year 2030. One of the advantages of conducting the analysis at the global economy level is that the results of this paper can then be compared with some of the results from international organizations like the International Energy Agency who makes forecasts of oil consumption and energy usage to 2030.

2. Literature review

To date there have been several published papers looking at the relationship between renewable energy consumption and various macroeconomic variables (like income, oil

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[2] This does not include 143 billion barrels of oil from the Alberta tar sands.

[3] In 2009, Saudi Arabia, Iran, Iraq, and Kuwait accounted for 19.8%, 10.3%, 8.6% and 7.6% respectively of the world's proven oil reserves.

[4] The numbers in parentheses represent each country's respective share of global oil consumption.

[5] In January 2011, the US imported close to 9 million barrels of oil per day. At an average price of $89 per barrel, the monthly bill for imported oil was $24.8 billion dollars.

[6] In early 2011, the US federal budget deficit was estimated at $1.6 trillion dollars.

prices, capital, labour) at the country or regional level (see for example, Apergis & Payne, 2010a, 2010b, 2011; Chang et al., Lee, 2009; Chien & Hu, 2007,2008; Marques et al., 2010; Menyah & Wolde-Rufael, 2010; Sadorsky, 2009a, 2009b)[7]. The consensus from most of this research is that increases in income are a major driver behind increased renewable energy consumption.

Chien and Hu (2007) use data envelope analysis to analyze the effects of renewable energy on the technical efficiency of 45 economies over the period 2001-2002. They find that increasing the use of renewable energy improves an economy's technical efficiency while increasing the use of traditional energy (fossil fuel) decreases technical efficiency.

Chien and Hu (2008) use structural equation modeling techniques to analyze the effects of renewable energy on GDP for 116 countries in 2003. Their results show that renewable energy correlates positively with capital formation and that increasing the use of renewable energy increases GDP through the impact the impact on capital formation. Increasing the use of renewable energy has little impact on the trade balance.

Sadorsky (2009a) uses vector autoregression techniques to analyze the relationship between renewable energy consumption, income, oil prices and CO2 emissions in the Group of 7 (G7) economies over the period 1980-2005. In the long-term, increases in real GDP per capita and carbon dioxide emissions per capita are found to be major drivers behind increases in G7 renewable energy consumption per capita.

Sadorsky (2009b) uses panel cointegration techniques to investigate the relationship between renewable energy consumption and GDP for a sample of 18 emerging economies followed over the period 1994-2003. In the long-term, increases in real GDP per capita are found to be a major driver behind increases in renewable energy consumption per capita for emerging economies. No short-term evidence of statistically significant Granger causality is found between GDP and renewable energy consumption.

Chang et al. (2009) use threshold econometric techniques to investigate the relationship between economic growth and renewable energy supply for OECD member countries over the period 1997 to 2006. The threshold approach allows for a distinction on how renewable energy supply depends upon different economic growth regimes (like high or low). They find that countries characterized by high economic growth are able to respond to high energy prices with increases in renewable energy. Countries with low economic growth tend to be relatively non-responsive to energy price changes.

Apergis and Payne (2010a) use panel cointegration techniques to examine the relationship between renewable energy consumption and economic growth for a panel of 20 OECD countries over the period 1985-2005. The theoretical framework uses an aggregate production function relating output to labour, capital, and renewable energy. They find evidence of bidirectional causality between renewable energy consumption and economic growth in both the short-run and the long-run.

Apergis and Payne (2010b) use panel cointegration techniques to examine the relationship between renewable energy consumption and economic growth for a panel of 13 Eurasia countries over the period 1992-2007. As in Apergis and Payne (2010a) the theoretical model is based upon an aggregate production function which relates capital, labour, and renewable energy to output. They find empirical support for a feedback relationship between renewable energy consumption and output.

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[7] In the macroeconomic-energy literature, renewable energy is usually defined as non-hydro electricity generated from geothermal, wind, solar, tide and wave, wood, waste, and biomass.

Marques et al. (2010) uses panel regression techniques to investigate the relationship between renewable energy consumption, political factors, socioeconomic factors, and country specific factors for a panel of 24 European counties covering the period 1990-2006. They find that lobby efforts from the fossil fuel sector, and CO2 emissions reduce renewable energy consumption, while reducing energy self sufficiency promotes renewable energy consumption.

Menyah and Wolde-Rufael (2010) use vector autoregression techniques to study the relationship between carbon dioxide emissions, renewable energy consumption, nuclear consumption and real GDP for the US over the period 1960-2007. They find causality running from nuclear energy consumption to CO2 emissions but no causality running from renewable energy consumption to CO2 emissions. There is evidence of causality running from GDP to renewable energy.

Apergis and Payne (2011) use panel cointegration techniques to examine the relationship between renewable energy consumption and economic growth for a panel of 6 Central American countries over the period 1980-2006. Results from a panel error correction model indicate bidirectional causality between renewable energy consumption and economic growth in both the short- and long-run.

3. Empirical model

A vector autoregression (VAR) is used to empirically investigate the relationship between renewable energy consumption, income, oil consumption, and oil prices. One of the advantages of using a VAR is that the researcher does not need to provide prior assumptions about which variables are response variables and which variables are explanatory variables because in a VAR all variables are treated as endogenous. This means that in a VAR, each variable depends upon the lagged values of all the variables in the system. This allows for a much richer data structure that can capture complex dynamic properties in the data (Brooks, 2002).

A vector autoregression can be written in the following way.

$$y_t = B_0 + \sum_{j=1}^{p} B_j y_{t-j} + u_t \, , \Sigma(u_t u_t^{'}) = \Sigma \qquad (1)$$

In the above equation, the variable y is a n vector of endogenous variables, B_0 is a n vector of constants, and B_j is a nxn matrix of regression coefficients to be estimated. The error term, u, is assumed to be independent and identically distributed.

The VAR is estimated using annual data on global renewable energy consumption, income (GDP), oil consumption and oil prices from 1980 to 2008. The time frame is determined by data availability on renewable energy consumption. In estimating the VAR, all variables are expressed in natural logarithms in order to reduce heteroskedasticity. A linear time trend is included in the estimation of the VAR. The estimated coefficients from a VAR are of little use by themselves and it is usual to use impulse response functions to investigate the dynamic interaction between variables in a VAR. Analysis proceeds by estimating the model and using impulse response functions to investigate the dynamic interaction between the variables. The outcome of this analysis can then be used to provide forecasts and make policy recommendations.

4. Data

For this study, annual data over the period 1980-2008 is collected on renewable energy generation (REN), income (RGDP), oil consumption (OILCONSUMPTION), and real oil prices (ROIL). It is difficult to obtain data on renewable energy consumption and so following other authors, data on renewable energy generation is used as a proxy for renewable energy consumption. Since electricity cannot be stored, the difference between renewable energy consumption and renewable energy generation is not likely to be large. World renewable energy generation (defined as non-hydro electricity generated from geothermal, wind, solar, tide and wave, wood, waste, and biomass) data is available from the US EIA[8]. Data on world GDP is available from the World Bank online data base[9]. Data on world oil consumption and West Texas Intermediate crude oil prices are available from BP (2010). Oil prices are average oil prices for the year. Renewable energy is measured in billions of kilowatt hours (KW-H), real GDP is measured in 2000 US dollars, oil prices are measured in US dollars per barrel, and oil consumption is measured in thousands of barrels per day. Real oil prices are constructed by deflating nominal oil prices by the US CPI (available from the Federal Reserve Economic Database)[10].

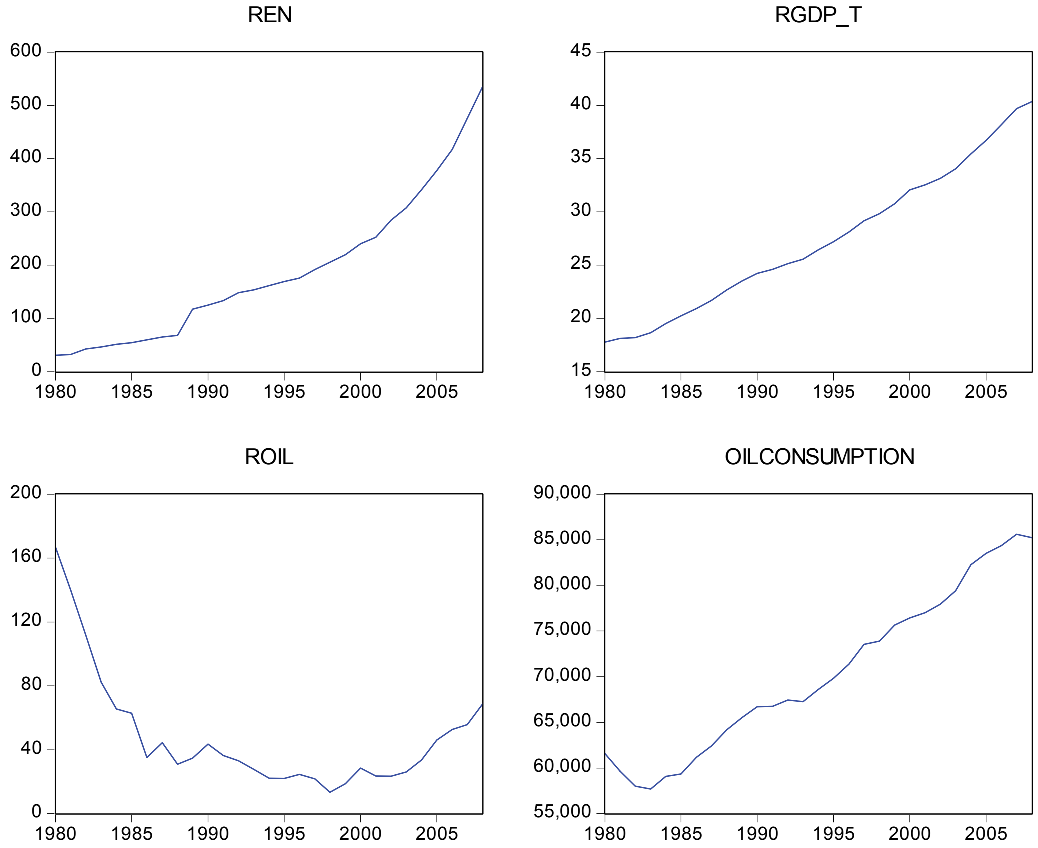

Fig. 1. Data plots

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[8] http://www.eia.doe.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=6&pid=29&aid=12
[9] http://databank.worldbank.org/ddp/home.do?Step=12&id=4&CNO=2
[10] http://research.stlouisfed.org/fred2/

Data plots are shown in Figure 1. Real world GDP, measured in trillions of US 2000 dollars (RGDP_T), has been growing along a linear trend line. Since 2000, global renewable energy consumption has been growing faster than in the period before 2000. Notice how real GDP and oil consumption tend to move upwards over time with similar slopes. Real oil prices display a U shaped pattern with the maximum value obtained in 1980. Real oil prices in 2008 are half of their value in 1980.

	REN	RGDP	ROIL	OILCONSUMPTION
Mean	10.198	2.926	-3.173	1.162
Median	8.266	3.207	-2.494	1.492
Maximum	54.345	4.563	42.619	3.511
Minimum	3.384	0.331	-58.167	-3.142
Std. Dev.	9.761	1.044	25.351	1.577
Skewness	3.626	-0.493	-0.183	-1.163
Kurtosis	16.470	2.579	2.337	4.306
t stat	5.528	14.830	-0.662	3.899
Jarque-Bera	273.032	1.342	0.670	8.299
Probability	0.000	0.511	0.715	0.016
Observations	28	28	28	28

Variables are calculated as log returns

Table 1. Summary statistics over 1980-2008 for variables in % growth rates

Table1 shows summary statistics for the variables measured in percentage growth rates. The average annual growth rate for renewable energy is 10.198% per year and this value is only slightly larger than its standard deviation. Real GDP has a higher average annual growth rate (2.926%) than oil consumption (1.162%). Real oil prices have a negative average annual growth rate and real oil prices also have the largest standard deviation (about 7 times the size of the absolute mean value). The t statistics indicate that the average annual growth rates are statistically significant for each of renewable energy, GDP, and oil consumption.

	REN	RGDP	ROIL	OILCONSUMPTION
REN	1.000	-0.016	0.123	-0.051
RGDP	-0.016	1.000	0.250	0.734
ROIL	0.123	0.250	1.000	0.184
OILCONSUMPTION	-0.051	0.734	0.184	1.000

Table 2. Correlations for variables measured in growth rates

Table 2 reports ordinary correlation coefficients. Renewable energy consumption correlates positively with real oil prices and negatively with each of the other two data series. The highest correlation is between real GDP and oil consumption (0.734).

5. Empirical results

In estimating the VAR, all variables are expressed in natural logarithms. A linear time trend is included in the estimation of the VAR. The lag length, p, of the VAR is chosen using the approach of Toda and Yamamoto (1995). Their approach to modeling is to estimate the VAR in levels and use a conventional lag length selection criteria like AIC or SIC to select the lag length and then to add an extra lag for the possibility that some or all of the variables contain unit roots. The Toda and Yamamoto (1995) approach does not require pre-testing for cointegration between the variables and can accommodate VAR models where some variables have unit roots and some variables are stationary. For the renewable energy consumption, income, oil consumption, and oil price VAR model, the SIC selects a lag length of one. Adding one extra lag length for the possibility that some or all of the variables contain a unit root establishes a VAR with p=2[11]. Since impulse response functions are used to interpret the results, some care must be taken to ensure that the VAR is stable because, strictly, speaking, impulse response functions are only valid if the VAR is stable (Lutkepohl, 2005). If the modulus of each eigenvalue of the matrix B is strictly less than one the estimated VAR is stable. Figure 2 shows the inverse roots of the AR characteristic polynomial are each less than unity, which satisfies the stability condition.

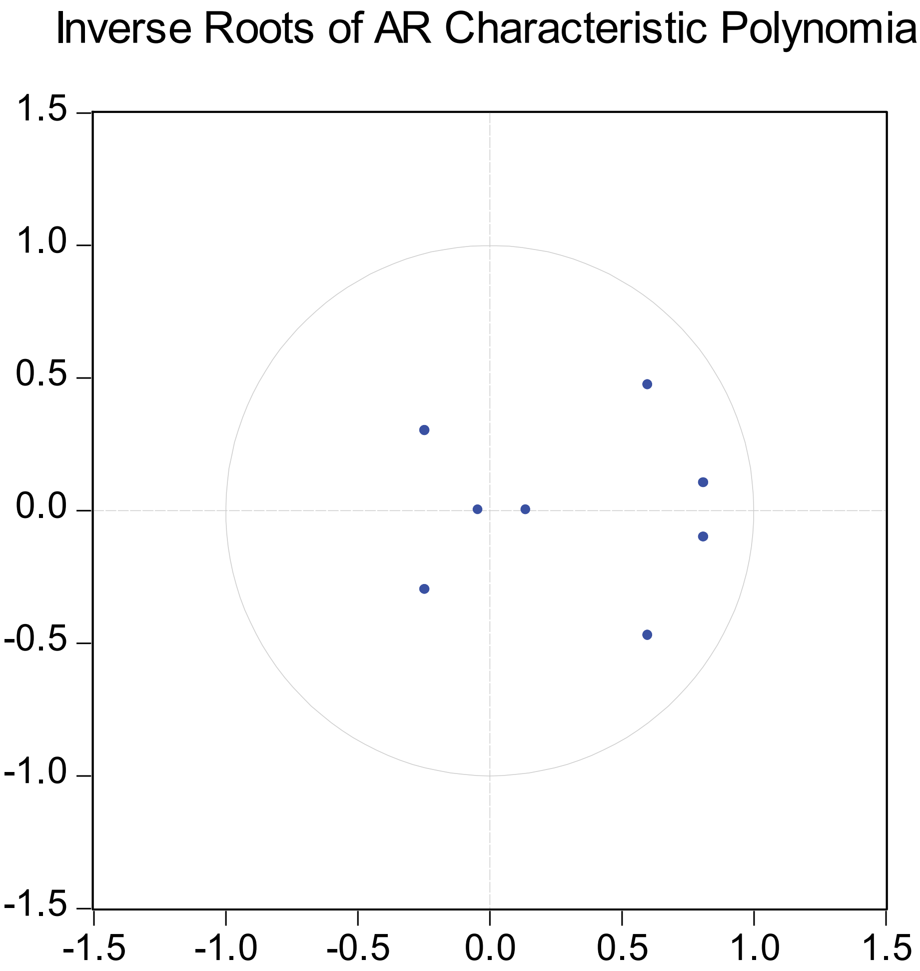

Fig. 2. Stability for VAR with 2 lags

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[11] All estimation was carried out using Eviews 7.0.

Table 3 reports LM tests for no autocorrelation of the residuals. All p values are larger than 1% (and only one p value is smaller than 5%) indicating that the residuals do not exhibit any strong evidence of autocorrelation. Normality tests confirm that at the 5% level, the residuals from the VAR are normally distributed (Table 4). The results of Figure 2, and Tables 3 and 4 indicate the VAR is adequately specified and can be used for constructing useful impulse response functions.

Lags	LM-Stat	Prob
1	21.62	0.16
2	26.88	0.04
3	16.42	0.42
4	14.55	0.56
5	9.81	0.88
6	9.23	0.90
7	11.82	0.76
8	8.39	0.94
9	18.81	0.28
10	16.93	0.39
11	23.09	0.11
12	21.11	0.17

Probs from chi-square with 16 df.

Table 3. LM tests on residuals

Component	Jarque-Bera	df	Prob.
1	2.218373	2	0.3298
2	4.695628	2	0.0956
3	3.448962	2	0.1783
4	3.670008	2	0.1596
Joint	14.03297	8	0.0809

Table 4. Normality tests on residuals

Figure 3 reports the generalized impulse response functions of each variable in response to a one standard deviation shock to each of the other variables[12]. The impulse responses are drawn with plus and minus 2 standard error bands to form 95% confidence intervals. As expected, each variable responds positively and statistically significantly to its own shock. The more interesting results are how a variable responds to shocks from other variables.

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[12] Generalized impulse response functions, which are not sensitive to the ordering of the variables in the VAR, are reported.

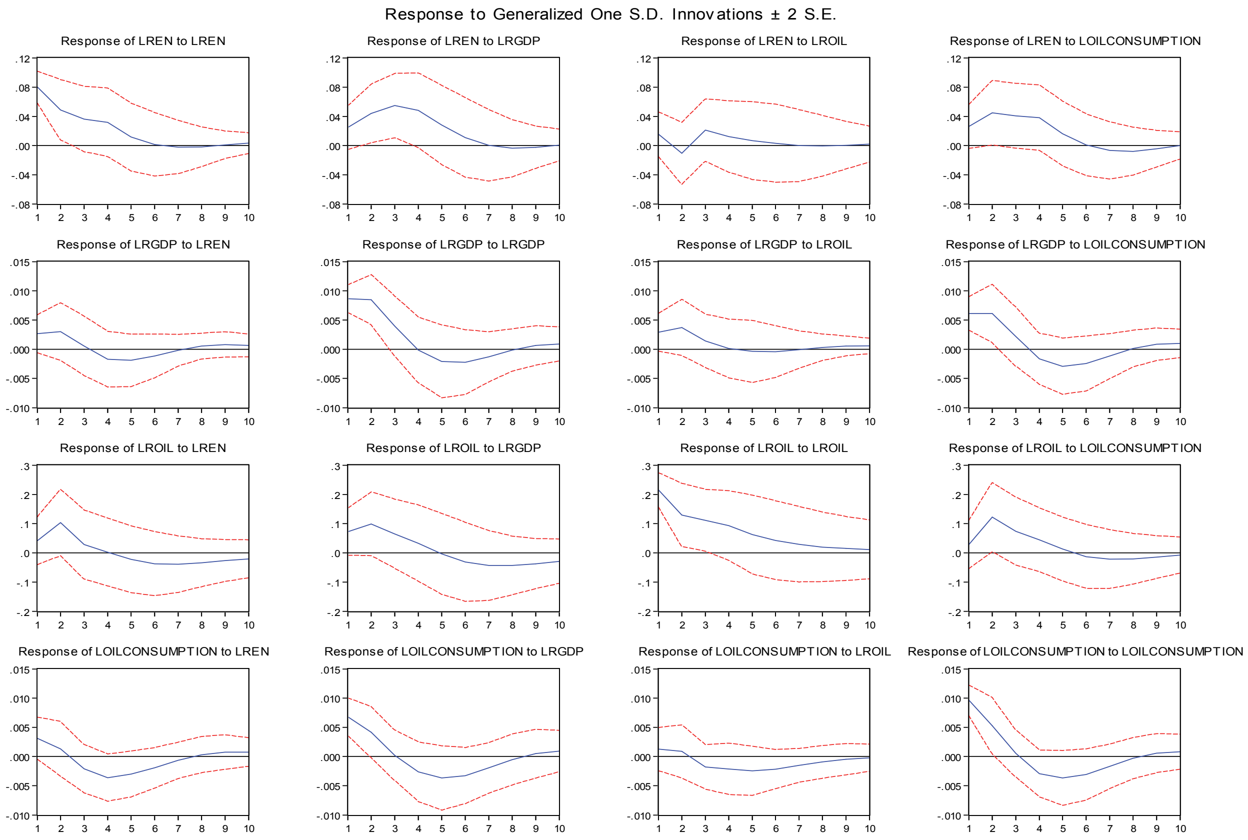

Fig. 3. Impulse response functions

A one standard deviation shock to income has a positive and statistically significant impact on renewable energy consumption for four years. This result is important in establishing that global consumption of renewable energy increases with increases in global income. A one standard deviation shock to oil consumption has a positive and statistically significant impact on renewable energy consumption for three years. This result is consistent with the pattern of global energy consumption over the period 1980-2008. As global energy consumption has risen specific sectors like oil and renewable have grown and so we expect to see a relationship between oil consumption and renewable energy consumption (Table 1). These results are important in establishing that increases in income and oil consumption are each important drivers of increased renewable energy consumption.

A one standard deviation shock to real oil prices has a positive and statistically significant impact on income in the first year of the shock. A one standard deviation shock to oil consumption has a positive and statistically significant impact on income for two and a half years. This result is important in establishing that increases in oil consumption leads to increase economic growth. This makes sense when one thinks about the production side of the economy. Energy is an essential input into the production of most goods and services and increasing the factor s of production like capital, labour and energy increases output.

A one standard deviation shock to income increases real oil prices over the first two years and this result is marginally statistically significant. In year two, real oil prices respond in a positive and statistically significant way to a one standard deviation shock to oil consumption.

A one standard deviation shock to income has a positive and statistically significant impact on oil consumption for years one and two. This result is important in establishing that higher economic growth leads to greater oil consumption. Oil consumption does not respond to shocks to real oil prices in a statistically significant way.

Figure 4 reports accumulated impulse response function. Whereas Figure 3 traces out the effects of a shock across time, Figure 4 reports the accumulated effect of a shock across time. The accumulated response of renewable energy consumption to a shock to income is positive and statistically significant for 6 years. The accumulated response of renewable energy consumption to a shock to oil consumption is positive and statistically significant for 5 years. The accumulated response of real oil prices to a shock to oil consumption is positive and statistically significant for 3 years. The accumulated impulse response functions in Figure 4 also more clearly show the feedback relationship between income and oil consumption. The accumulated response of income to a shock to oil consumption is positive and statistically significant for 4 years. The accumulated response of oil consumption to a shock to income is positive and statistically significant for 4 years.

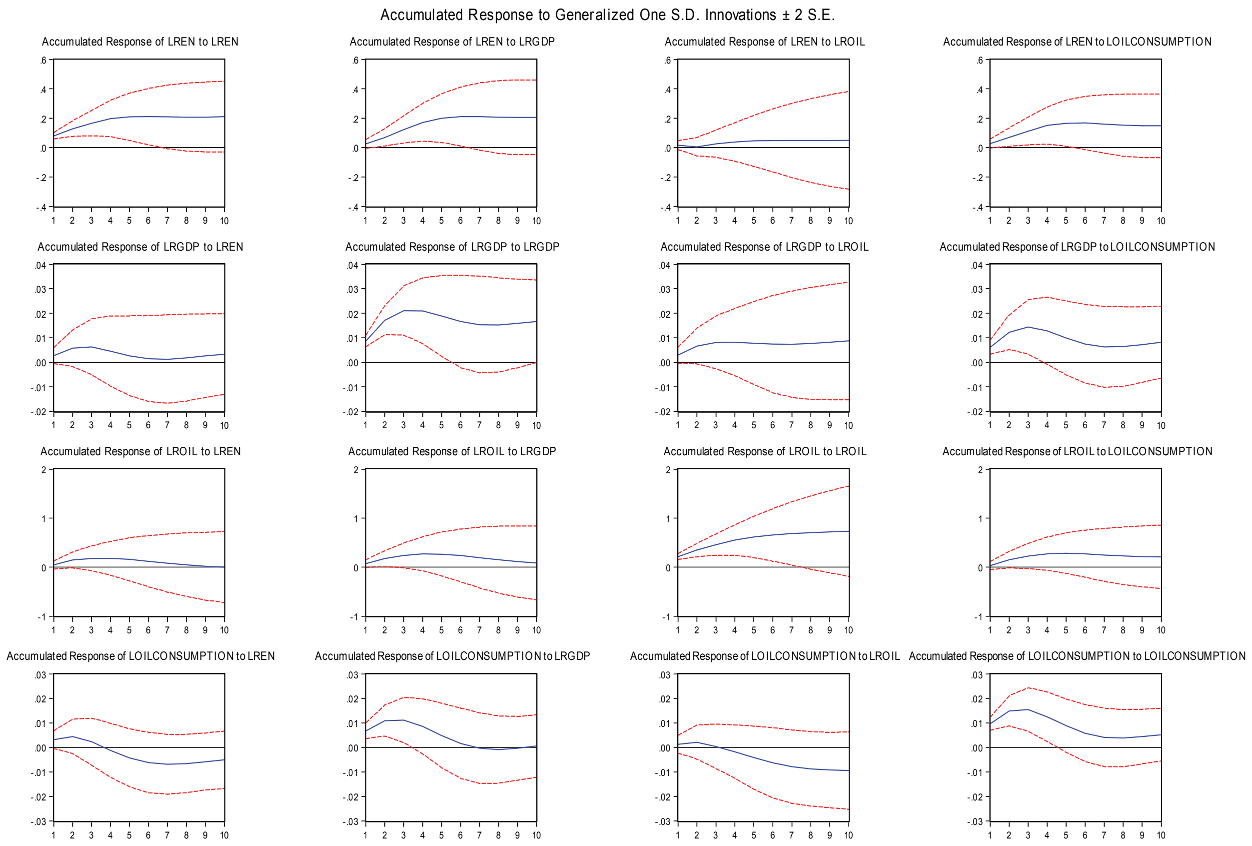

Fig. 4. Accumulated impulse response functions

6. Forecasts

The VAR model can also be used to construct out-of-sample dynamic forecasts over the period 2009-2030. Two sets of forecasts are presented, dynamic and stochastic. In constructing dynamic forecasts, historical data for lagged endogenous variables are used if they are dated prior to the first period of forecasting. After words, forecasts from previous periods are used as lagged endogenous variables. For the dynamic forecasts, the error terms in equation (1) are ignored. For stochastic forecasts, the error terms in equation (1) are modeled using Monte Carlo simulation techniques. The model predicts a distribution of outcomes for each variable at each observation which facilitates the computation of standard error bands. Stochastic forecasts are produced using Monte Carlo simulation techniques assuming each endogenous variable is distributed normally. The number of replications is set at 10,000[13].

The VAR model is estimated over the period 1980-2008 and dynamic forecasts are made over the period 2009-2030. The dynamic forecasts show that renewable energy consumption, GDP, and oil consumption are each forecast to rise along a fairly straight trend line. Real oil prices dip in 2010 before resuming an upward trend.

Table 5 summarizes the dynamic forecasts for the years 2015, 2020, 2025, and 2030 in a table, making it easier to read the actual forecasted values. In the year 2030, global oil consumption is forecast to be 117 million barrels of oil per day, and renewable energy consumption is forecast to be 3.4 trillion KW-H. Between 2009 and 2030, oil consumption is predicted to grow by 1.5% per year and renewable energy consumption is predicted to growth by 8.5% per year. Real global GDP (in 2000 US dollars) is forecasted to be $77 trillion in 2030. The VAR model forecasts real (2000 US dollar) oil prices. In order to get a forecast of nominal oil prices, the US CPI must be forecast. The US CPI is modelled over the period 1980-2008, using a linear trend (intercept is equal to -10.66 and slope coefficient is equal to 4.09). The R square from this regression is 98%. Real oil prices are forecasted to be $247 per barrel in 2030 and nominal oil prices are forecasted to be $216 per barrel in 2020 and a whopping $550 per barrel in 2030.

These forecasts for oil consumption and renewable energy consumption are fairly close to those provided by the International Energy Agency (IEA, 2007). The International Energy Agency (2007, 80), for example predicts global oil consumption of 116 million barrels per day in 2030. Over the period 2005-2030 oil is expected to have an average annual growth rate of 1.3% while renewable energy consumption has an average annual growth rate of 6.7%[14].

Stochastic dynamic forecasts are shown in Figure 6 along with plus and minus two standard error bands. Oil consumption and real GDP are each estimated fairly precisely as shown by the tightness of the error bands. In 2030 global oil consumption is forecast at 117 million barrels per day and the 95% confidence interval ranges from 114 million barrels per day to 120 million barrels per day. Renewable energy consumption is reasonably well estimated. In 2030, renewable energy consumption is forecast at 3.4 trillion KW-H with a 95% confidence interval ranging from 2.6 trillion KW-H to 4.4 trillion KW-H. The greatest uncertainty is associated with the forecasts of real oil prices. In 2030 real oil prices are forecast at $247 per barrel with a 95% confidence interval that ranges from $118 per barrel to $516 per barrel. This wide confidence interval puts nominal oil prices in 2030 between $263 per barrel and $1149 per barrel.

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[13] A higher number of replications increases precision but for this particular model there is not much difference in the forecasts calculated from 10,000 replications compared to those calculated from 5,000 replications.

[14] The IEA forecasts do change from year to year depending upon global economic conditions. IEA (2009), for example, in response to the global recession of 2008-2009 forecasts oil consumption in 2030 to be 105 million barrels per day.

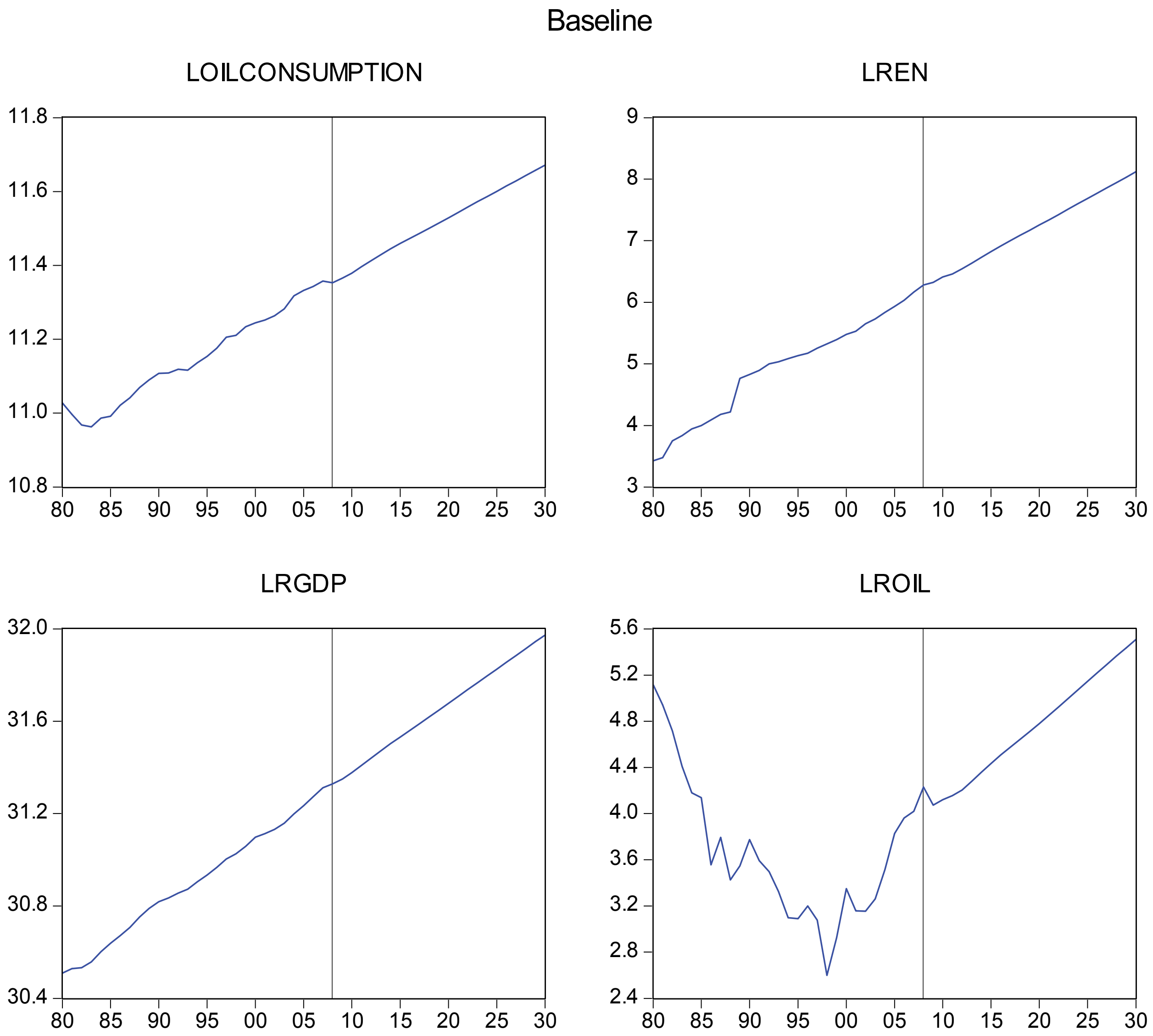

Fig. 5. Dynamic forecasts

Year	Oil consumption	Renewable	RGDP	Real Oil	Nominal Oil
2015	94753	920	49455	84	136
2020	101601	1414	57209	119	216
2025	109148	2180	66352	172	347
2030	117175	3359	76914	247	550

Oil consumption measured in 1,000s of barrels per day, renewable energy consumption in billions of KW-H, RGDP in billions of 2000 US dollars, and real oil prices in 2000 US dollars. Nominal oil prices measured in current US dollars per barrel.

Table 5. Dynamic forecasts

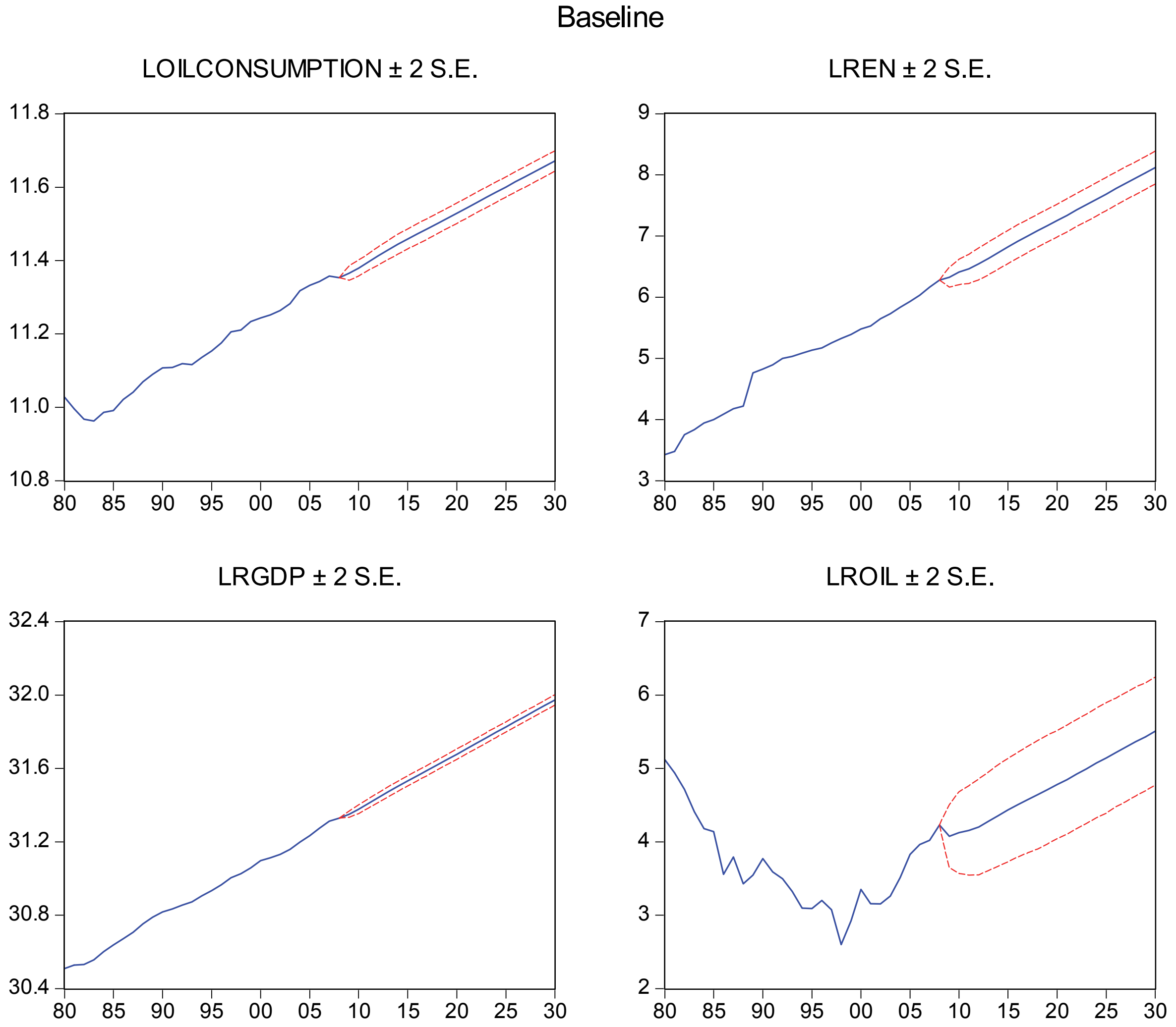

Fig. 6. Stochastic dynamic forecasts

A few comments are in order regarding the assumptions under which the forecasts were made. The forecasts are made under the assumptions of no major energy policy or environmental policy changes that would dramatically reduce the consumption of oil and fossil fuel sources in favour of more renewable energy. In other words, the assumption is made that no major global climate change treaty, like a successor to Kyoto, is signed and ratified that creates a big reduction in the usage of fossil fuels. The forecasts also assume that peak oil will not result in severe shortages of oil such that the oil consumption forecasts cannot be met. By comparison, the International Energy Agency (2010) predicts that a combination of factors including slowing global economic growth, rising oil prices, increased usage of renewable, and concerns about peak oil (mostly realized through rising oil prices) will limit global oil consumption to 100 million barrels of oil per day in 2035.

7. Policy implications

The results from impulse response functions show that positive shocks to income increase renewable energy consumption. This is an important result showing that increasing global GDP will increase the consumption of renewable energy. This means that economic policies that speed economic growth and development will lead to increases in renewable energy consumption. Rising incomes lead to more disposable income and individuals with higher incomes have more concern for the environment which increases the usage of renewable energy. From a policy perspective, government policy at the national and international level aimed at increasing income is good for increasing renewable energy consumption. Government policies that can increase income and wealth generation include stable and well designed monetary and fiscal policy, well functioning labour markets, policies that focus on increasing innovation and productivity, and an economic landscape free of corruption and rent seeking. While these policies need to be enacted at the national level, international organizations like the IMF, World Bank, and United Nations need to promote the benefits of sound economic and environmental policies to their member countries.

The results from impulse response functions show that positive shocks to oil consumption increase renewable energy consumption. The relationship between renewable energy consumption and oil consumption is of less interest because as global energy consumption grows so too do the individual energy sector components like oil and renewables.

The results from impulse response functions show that positive shocks to real oil prices have very little impact on renewable energy consumption. This result is somewhat counter intuitive to what is often presented in the popular media. Media stories often point to higher oil prices as a primary driver behind the expansion of the renewable energy business and increases in renewable energy consumption. This view is also supported by economic theory. Rising oil price should create incentives to substitute away from expensive fossil fuels towards alternatives like renewable. Over the period which the VAR was estimated (1980-2008) real oil prices were not continuously rising but instead resembled more of a U shape. In fact, over the estimation period, the highest recorded real oil prices were in 1980. The rather weak relationship between oil prices and renewable energy has been noted by others. In a somewhat different context, Henriques and Sadorsky (2008) and Sadorsky (2010) have looked at the impact of oil prices on the stock prices of clean energy companies. Henriques and Sadorsky (2008) find that the stock prices of clean energy companies are more responsive to changes in technology then to changes in oil prices. In a slightly different context, investigating the relationship between risk factors and clean energy stock prices, Sadorsky (2010) finds that company sales growth has a negative impact on company risk (CAPM beta) while oil price increases have a positive impact on company risk.

Looking into the future, it is expected that if real oil prices rise by enough, then a substitution effect from oil to renewable energy will follow. The uncertainty is that it is not clear just how high oil prices will have to rise in real terms to create a significant substitution effect. As Figure 1 shows, real oil prices in 2008 were just half of their value in 1980. In a world of rapidly rising oil prices, government policy can play a role in speeding up the substitution from oil to renewable energy.

What if issues like climate change, resource security, or resource depletion become major constraining factors, and that it is not possible to secure 117 million barrels of oil per day in 2030 or major climate change initiatives are implemented to drastically reduce the amount of CO_2 being emitted? In these cases, additional government policy is called for to further increase the usage of renewable energy. One approach to increasing the usage of renewable energy consumption at the global economy level is to use the stabilization wedges approach (http://cmi.princeton.edu/wedges/) advocated by the Carbon Mitigation Initiative at Princeton University (http://cmi.princeton.edu/).

The Carbon Mitigation Initiative (CMI) identifies that currently, 8 billion metric tons of carbon dioxide are being released globally into the atmosphere from the burning of fossil fuels. In the next 50 years this amount will double. The lead researchers on the project, Robert Socolow and Stephen Pacala, have identified 15 stabilization wedges with each wedge representing a strategy to reduce annual carbon emissions by 1 billion metric tons[15]. The technology currently exists to make each one of these wedges operational. The efficiency category contains four wedges (raise the fuel economy of 2 billion cars from 30 mpg to 60 mpg, reduce the average number of miles travelled from 10,000 to 5,000, increase efficiency in heating, cooling, lighting, and appliances by 25%, increase coal-fired power plant efficiency from 40% to 60%). The fuel switching category has one wedge (replace 1400 coal fired electric plants with natural gas-powered facilities). The carbon capture and storage category has three wedges (introduce carbon capture and storage at 800 large coal-fired plants or 1,600 natural gas-fired plants, use carbon capture in carbon derived hydrogen plants, use carbon capture in carbon derived synthetic fuels plants). The nuclear category has one wedge (double the current global nuclear energy capacity). The wind category has one wedge (increase wind electricity capacity by 15 times relative to today for a total of 2 million windmills). The solar category has two wedges (install 350 times the current capacity of solar electricity, use 40,000 square kilometers of solar panels to produce hydrogen for fuel cell powered cars). The biomass fuels category has one wedge (increase ethanol production by 15 times by creating biomass plantations with area equal to 1/6 of world cropland). The natural sinks category has two wedges (eliminate tropical deforestation, adopt conservation tillage practices in all agricultural worldwide).

According to the CMI calculations, global carbon emissions from burning fossil fuels are currently around 8 billion metric tons a year. They identify three possible paths for carbon emissions. Path one is to continue along the same current business as usual trend line for carbon emissions. Following this path results in a projected 16 billion metric tons of carbon dioxide being released into the atmosphere from burning fossil fuels in 2057. In 2057, carbon dioxide emissions would reach 800 ppm and average global temperatures would rise 9°F. Path two is designed to hold carbon emissions from fossil fuels at today's rate of 8 billion metric tons per year. This means that 8 wedges have to be cut by 2057. Further cuts are required after 2057. In 2057, this path leads to a carbon concentration of 525 ppm and an average global temperature increase of 5.4°F. The third option calls for a reduction in emissions below the present value. A total of 12 wedges are cut. In 2057, this path leads to a carbon concentration of 450 ppm and an average global temperature increase of 3.6°F. One of the real advantages of the carbon wedge stabilization concept is that each wedge represents a reduction in carbon dioxide emissions of one billion metric tons and that the technology currently exists to make each wedge fully operational.

Many approaches to increasing the usage of renewable energy and reducing the usage of fossil fuels advocate taxing fossil fuels and subsidizing renewables and in doing so create incentives to shift consumption form fossil fuels to renewables. Another approach is to focus on energy security and create industrial policy to reduce the dependence on oil.

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[15] http://cmi.princeton.edu/wedges/intro.php

Some, like Lovins et al (2004) have already laid out a viable road map for how, by 2050, the United States economy can be flourishing with no oil at all. They advocate investing $180 billion over the next decade to eliminate U.S. oil dependence. The U.S. current imports approximately 66% of the oil consumed on a daily basis. Rather than spending money on importing oil, investments can be made to lessen and gradually eliminate the dependence on imported oil. In their calculations, this investment will result in a gross savings of $130 billion. They advocate using a four step approach that relies on creative destruction to revitalize the energy sector. First, oil efficiency must be doubled by using advanced but proven technologies to design and build ultralight vehicles. Second, business and public policies must be developed to accelerate the design and manufacturing of light weight materials, like carbon-fiber composites, that can be used in buildings, vehicles, heavy trucks and airplanes. Third, petroleum products must be replaced with biofuels. Fourth, increase efficiency in the natural gas sector to save half the projected 2025 use of natural gas. These savings will mean more natural gas can be used to make hydrogen and this will provide a convenient secure path to the hydrogen economy. While this four step plan is specifically designed for the United States, there is no reason why parts or all of this strategy could not be adopted in other countries.

8. Conclusions

This paper develops and estimates a VAR model of renewable energy consumption, income, oil consumption, and real oil prices in order to investigate the dynamic interaction between these variables. The model is estimated using global data over the period 1980-2008. The VAR model fits the data well. The results from impulse response functions show that positive shocks to income or oil consumption increase renewable energy consumption. Shocks to real oil prices have little impact on renewable energy consumption.

One of the important policy implications of these results is that government policy at the national and international level aimed at increasing income is good for increasing renewable energy consumption. Examples of good government policies that can increase income and wealth generation include stable and well designed monetary and fiscal policy, well functioning labour markets, policies that focus on increasing innovation and productivity, and an economic landscape free of corruption and rent seeking. While these policies need to be enacted at the national level, international organizations like the IMF, World Bank, and United Nations need to promote the benefits of sound economic and environmental policies to their member countries.

If other issues like climate change, resource security, or resource depletion become major constraining factors, then additional government policy is called for to further increase the usage of renewable energy. Government can tax fossil fuels and subsidize renewable energy. In particular government can provide subsidies in the form of R&D credits, low cost loans, and production tax credits to speed the development and roll out of renewable energy products. Government can provide renewable portfolio standards and subsidies to consumers and early adopters of new renewable energy products. Government can also create new energy efficiency and carbon-fiber composites industrial policy designed to lessen the dependence on oil. This new industrial policy would increase energy efficiency by using new existing technologies to design and build ultralight vehicles and to accelerate the design and manufacturing of light weight materials, like carbon-fiber composites, that can be used in buildings, vehicles, heavy trucks and airplanes.

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Planet Earth 2011 - Global Warming Challenges and Opportunities for Policy and Practice
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The failure of the UN climate change summit in Copenhagen in December 2009 to effectively reach a global agreement on emission reduction targets, led many within the developing world to view this as a reversal of the Kyoto Protocol and an attempt by the developed nations to shirk out of their responsibility for climate change. The issue of global warming has been at the top of the political agenda for a number of years and has become even more pressing with the rapid industrialization taking place in China and India. This book looks at the effects of climate change throughout different regions of the world and discusses to what extent cleantech and environmental initiatives such as the destruction of fluorinated greenhouse gases, biofuels, and the role of plant breeding and biotechnology. The book concludes with an insight into the socio-religious impact that global warming has, citing Christianity and Islam.

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