E.ON Energy Research Center
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FCN Working Paper No. 10/2013

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June 2013

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Publisher: Prof. Dr. Reinhard Madlener
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What if Energy Time Series are not Independent? Implications for Energy-GDP Causality Analysis

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June 2013

Abstract

Time series of electricity, petroleum products, and renewables are found to be highly correlated with total energy consumption. Applying this insight to the huge literature on energy-GDP causality explains that the results of energy-GDP causality tests frequently coincide with the results of energy type-GDP tests. Using the test by Toda-Yamamoto in combination with a cointegration-based testing approach, we detect such cases of concordance for 92 per cent of the countries in our sample of 65 countries. As a consequence, it is difficult to draw specific economic conclusions regarding single types of energy from bivariate causality analysis.

Keywords: Energy, GDP, Granger causality, Correlation, Electricity, Petroleum products, Renewables, Toda-Yamamoto, Johansen-Juselius

JEL: Q43, C32, C52

1. Introduction

The seminal paper by Kraft and Kraft (1978) on energy-GDP Granger causality initiated an ongoing and highly contentious debate on the direction of causality.[2] Most recently, however, there is growing evidence that the debate can be resolved. In a meta-regression analysis of a large sample of the literature on energy-GDP causality, Bruns et al. (2013) find that (total) energy consumption has some genuine causal connection with GDP. This finding corresponds to other recent contributions to the debate (e.g., Gross, 2012; Stern and Enflo, 2013).

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[1]Stephan Bruns is grateful to the German Research Foundation (DFG) for financial support through the program DFG-GK-1411: "The Economics of Innovative Change."

[2]This includes Granger causality from energy to GDP (or *vice versa*), bi-directional Granger causality, or no Granger causality. In the remainder of the paper, when talking about "causality", we always refer to the concept of Granger causality (Granger, 1969).

Apart from total energy consumption special attention is often given to the role of single types of energy (see Ozturk, 2010 and Payne, 2010 for an overview). "Electrification", "Oil Economy", and "Green Economy" are only a few keywords highlighting the economic relevance of the energy types electricity, petroleum products, and renewables.[3]

Our aim is to contribute to the politically relevant debate on energy type-GDP causality by putting more emphasis on statistical aspects of energy time series. We raise the question to what extent time series for different types of energy are independent of total energy. Our argument is based on the simple observation that total energy is an aggregate of all types of energy, which may result in statistical dependence between total energy and the energy types. It applies even more so if total energy and all types of energy fluctuate with GDP in a similar way, e.g., due to business cycles. As our principal contribution, we investigate whether this plausible statistical dependence is strong enough to interfere with tests of energy-GDP causality. If energy types are not sufficiently independent of total energy, energy type-GDP causality tests might match with total energy-GDP causality tests. If this is the case, it is difficult to draw specific economic conclusions regarding single types of energy from causality analysis.

In a sample of 65 countries, we find that different types of energy are highly correlated with total energy consumption. Using the test by Toda and Yamamoto (1995) as well as a VECM/VAR testing approach based on Engle and Granger (1987) for analyzing energy-GDP and energy type-GDP causality, we find that for at least one energy type results match for 92 per cent of the countries. Using a probit model we find that the probability of a match is increased when an energy type is correlated with total energy. The probability is lower if one energy type is cointegrated with GDP, but another is not.

The paper is organized as follows. In Section 2, we outline the theoretical background. The description of the dataset and the estimation strategy follows in Sections 3 and 4, respectively. In Section 5, we briefly discuss our findings. Section 6 concludes.

2. Theoretical Considerations

In the energy literature it is common to analyze the economic relevance of energy using causality tests of the energy-GDP relationship (Ozturk, 2010; Payne, 2010). Usually, the tests by Granger (1969), Sims (1972), Hsiao (1979), Engle and Granger (1987), Johansen-Juselius (1988; 1991), Toda and Yamamoto (1995), Pesaran and Shin (1999) and Pesaran et al. (2001) are applied to time series for different countries, by using different control variables, and so on. If one finds causality between energy and GDP, energy has particular relevance for the growth of the economy (or *vice versa*).

More recently, researchers tend to use disaggregate data to analyze energy-GDP causality in more detail. When doing so, however, statistical problems might arise when the variables under investigation do not

[3] Of course, specific economic relevance can also be attributed to coal, natural gas, nuclear, and other types of energy. As will be discussed in Section 3, we cannot consider these types of energy here for reasons of data availability.

share the same level of aggregation (see Gross, 2012 and Zachariadis, 2007 for a discussion of "appropriate pairs of variables" for energy-GDP causality analysis). With regard to the mostly studied relationship between energy and *total* GDP, it therefore follows that the *total* amount of energy consumptions should be considered for as well. Only total energy, i.e., energy at the highest level of aggregation, corresponds to all energy inputs needed for economy-wide production.[4]

Nevertheless, knowledge about the relationship between energy types, i.e., subaggregates of total energy, and GDP is desirable and particularly important for giving detailed energy policy advice. Petroleum products, for example, are essential for production and transportation of many goods, as well as consumer uses such as automobile fuel and heating. Electricity is generally assumed to be the highest quality type of energy with regard to economic usefulness per heat equivalent (Stern, 2011). Renewable types of energy are often considered as labor intensive and, hence, of particular economic importance (e.g., Frondel et al., 2010). So far, empirical analyses have been carried out for the energy types electricity (e.g., Altinay and Karagol, 2005; Tang and Tan, 2012), petrol (e.g., Lotfalipour et al., 2010; Zou and Chau, 2006), and renewable energy types (e.g., Payne, 2009; Vaona, 2012).[5]

In the remainder of this paper, we discuss energy type-GDP relationships in the light of some statistical peculiarities inherent to (dis-) aggregate energy time series. The basic question we raise is, to what degree time series for different types of energy are independent of total energy. To a certain degree dependence may stem from the simple fact that total energy is the sum of all energy types. Moreover, assume that fluctuations of economic activity affect the consumption of all energy types in a similar way. The growth rates of the energy types are then likely to be correlated with total energy. Suppose further that annual growth rates of all energy types coincide over a longer period of time. The amount of statistical information provided by the different energy time series therefore might not be sufficient to distinguish different types of energy from total energy. In such a case, it cannot be excluded that results of causality tests between different types of energy and GDP just reproduce the findings of causality tests between total energy and GDP.

When giving advice for energy policy, however, it is necessary to have full knowledge about interdependencies among energy time series. Suppose that, for example, that petroleum products are found to cause GDP. In a bivariate causality test recommendations to further invest in petroleum infrastructure are justified only if the time series for petroleum products are sufficiently independent from the time series for total energy. Omitting the remaining energy sources from the test may result in omitted variables bias and falsely attribute the effect of total energy to petroleum products.

We can derive the following empirically testable hypotheses from our theoretical considerations. $H1a$:

[4]Of course, sectoral energy shares the same level of aggregation with sectoral GDP as well. In order to keep the number of results manageable, however, we limit our analysis to total energy and total GDP as the benchmark.

[5]Not forgetting the studies of energy type-GDP causality for coal (e.g., Wolde-Rufael, 2010) and natural gas (e.g., Zamani, 2007).

Time series for the energy types electricity, petroleum products, and renewables are not independent of total energy. $H1b$: Total energy-GDP and energy type-GDP causality tests do not match randomly. $H2$: The degree of non-independence between time series for single energy types and total energy explains the probability of a match between causality tests.

3. Data

We evaluate the validity of our hypotheses by using time series data on GDP (measured in constant local currency) for 65 countries from the World Development Indicators (World Bank, 2012). Data on energy consumption (measured in tons of oil equivalent) are taken from the International Energy Agency (2008). We include only those countries where all required energy times series are available, at least for 30 years. This is done both to increase consistency of the data and to avoid spurious results due to a lack of observations. Hence, we can account for total energy consumption, and electricity, petroleum products, and renewables (combustible renewables and waste, geothermal, hydro, solar, and wind). Apart from the full sample of countries, we extend our analysis to different income groups as well: high income, upper middle income, lower middle income, and low income. Income groups are selected according to the World Bank List of Economies (World Bank, 2011).

4. Estimation Strategy

4.1. Correlation Between Total Energy and Different Types of Energy

In order to address $H1a$, we analyze the statistical dependence between total energy and the different types of energy. It allows us to find out to what extent single types of energy contain more statistical information than total energy. When evidence for a high degree of dependence is found, single energy types can be regarded as a proxy for total energy. In such a case the relationship between a single type of energy with GDP cannot be adequately quantified.

A common measure of statistical dependence is Pearson's correlation (e.g., Lee Rodgers and Nicewander, 1988). According to Granger and Newbold (1974) correlation may be spurious if time series are non-stationary. Since GDP and energy time series are very systematically found to be integrated of order one in prior studies on energy-GDP causality, we take first differences of the logged variables to analyze correlation between total energy and the different types of energy.

4.2. Matching of Causality Tests

In order to address $H1b$, we analyze whether a test for causality between a single type of energy and GDP yields the same results as a test between total energy and GDP. Since causality may run from energy to GDP (or *vice versa*), can be bi-directional, or absent, a "match" occurs only if an energy type-GDP causality test yields the same direction of causality as a total energy-GDP causality test.

We use two different estimation techniques to test causality, both of which are most widely used in the energy-GDP literature.[6] First, the test by Toda and Yamamoto (1995) is based on a Wald test in a Vector Autoregression Model (VAR) in levels. It can be applied irrespective of the degree of integration or presence of cointegration. According to Toda and Yamamoto, when a VAR in levels, with a true lag order p, is augmented by the number of lags equal the highest possible order of integration (d_{max}), a Wald test on the true independent lags (p) is asymptotically χ^2 distributed. Hence, causality can be tested within the following VAR:

$$\begin{bmatrix} Y_t \\ E_t \end{bmatrix} = \begin{bmatrix} \delta_{01} \\ \delta_{02} \end{bmatrix} + \sum_{i=1}^{p} \begin{bmatrix} \delta_{11,i} & \delta_{12,i} \\ \delta_{21,i} & \delta_{22,i} \end{bmatrix} \begin{bmatrix} Y_{t-i} \\ E_{t-i} \end{bmatrix} + \sum_{j=1}^{d_{max}} \begin{bmatrix} \delta_{11,p+j} & \delta_{12,p+j} \\ \delta_{21,p+j} & \delta_{22,p+j} \end{bmatrix} \begin{bmatrix} Y_{t-p-j} \\ E_{t-p-j} \end{bmatrix} + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \end{bmatrix}, \quad (1)$$

where Y denotes GDP and E energy. $i = 1, ..., p$ is the number of lags and $j = 1, ..., d_{max}$ the number of augmented lags. The number of lags is usually determined by a selection criterion such as the Akaike information criterion (AIC). We can test evidence for causality from energy to GDP by: $H_{0,ty}^{E} : \forall \delta_{12,i} = 0$. The opposite direction of causality, i.e. whether GDP causes energy, can be tested by: $H_{0,ty}^{Y} : \forall \delta_{21,i} = 0$.

We test $H_{0,ty}^{E}$ and $H_{0,ty}^{Y}$ for total energy-GDP causality, electricity-GDP causality, petroleum products-GDP causality, and renewables-GDP causality. The lag length is determined by the AIC with a maximum lag length of 4. Since the order of integration is usually found to be 1, we set d_{max} at 1. Finally, we calculate the percentage of causality tests where a match occurs.

In order to assess the magnitude of causality test matches, we calculate a reference scenario were matches occur only randomly. If, overall, the reference values are clearly exceeded, we conclude that matches do not occur randomly. For the Toda-Yamamoto test we consider a percentage of matches larger than 18.04% as evidence of non-random matches (see Technical Appendix for details).

Second, we use a cointegration-based testing approach for causal discovery. Here, it is prerequisite to test for cointegration before the causality test can be applied. For this purpose most studies on energy-GDP causality use the test by Johansen (1988; 1991). If an energy variable is found to be cointegrated with GDP, a Vector Error Correction Model (VECM) can be estimated to analyze causality between the two variables (Engle and Granger, 1987):

$$\begin{bmatrix} \Delta Y_t \\ \Delta E_t \end{bmatrix} = \begin{bmatrix} \gamma_{01} \\ \gamma_{02} \end{bmatrix} + \sum_{i=1}^{p-1} \begin{bmatrix} \gamma_{11,i} & \gamma_{12,i} \\ \gamma_{21,i} & \gamma_{22,i} \end{bmatrix} \begin{bmatrix} \Delta Y_{t-i} \\ \Delta E_{t-i} \end{bmatrix} + \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix} \begin{bmatrix} \beta_1 & \beta_2 \end{bmatrix} \begin{bmatrix} Y_{t-1} \\ E_{t-1} \end{bmatrix} + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \end{bmatrix}, \quad (2)$$

where Δ denotes the first difference operator. The coefficients α_1 and α_2 are error correction terms (ECT), measuring how the dependent variable reacts to deviations from the long-run equilibrium. We use the AIC

[6] Although the ARDL bounds testing approach by Pesaran and Shin (1999) and Pesaran et al. (2001) is often used in the literature on energy-GDP causality, it is an inappropriate model for causal discovery. The reason is that it assumes the direction of causality, *a priori* (see also Bruns et al., 2013).

to determine the lag length with a maximum lag length of 4. Long-run causality from energy to GDP can be tested by $H^E_{0,vecm} : \alpha_1 = 0$ using an F-test. The opposite direction of causality can be tested by $H^Y_{0,vecm} : \alpha_2 = 0$.

If the Johansen test does not indicate cointegration between energy and GDP, causality can still be analyzed in a VAR in first differences (VARfd):

$$\begin{bmatrix} \Delta Y_t \\ \Delta E_t \end{bmatrix} = \begin{bmatrix} \phi_{01} \\ \phi_{02} \end{bmatrix} + \sum_{i=1}^{p-1} \begin{bmatrix} \phi_{11,i} & \phi_{12,i} \\ \phi_{21,i} & \phi_{22,i} \end{bmatrix} \begin{bmatrix} \Delta Y_{t-i} \\ \Delta E_{t-i} \end{bmatrix} + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \end{bmatrix}, \tag{3}$$

Again, we use the AIC to determine the lag length with a maximum lag length of 4. Causality from energy to GDP can be tested by $H^E_{0,var} : \forall \phi_{12,i} = 0$ using an F-test. The opposite direction of causality can be tested by $H^Y_{0,var} : \forall \phi_{21,i} = 0$.

In order to assess the magnitude of causality test matches, we analyze the percentage of causality matches for the VECM/VARfd testing approach similar to the Toda-Yamamoto test. However, due to the pre-testing for cointegration as part of the VECM/VARfd testing approach, there are several ways how a match of causality tests occurs. Here, a match occurs if an energy type-GDP causality test corresponds to a total energy-GDP causality test when there is evidence for (i) long-term causality from energy to GDP in the VECM, (ii) long-term causality from GDP to energy in the VECM, (iii) long-term bi-causality in the VECM, as well as (iv) causality from energy to GDP in the VARfd (v) causality from GDP to energy in the VARfd, (vi) bi-causality in the VARfd, or (vii) neutrality in the VARfd. Note that neutrality cannot be found in the VECM, because cointegration already implies causality in at least one direction. Similar to the Toda-Yamamoto test we consider a percentage larger than 18.04% as evidence of non-random match (see Technical Appendix for details)

Finally, we conduct both estimation strategies at different significance levels of $\alpha = 0.01$, $\alpha = 0.05$, and $\alpha = 0.1$.

4.3. Explaining the Matching Probability

In order to address $H2$, we associate the dependence between total energy and the different types of energy with the probability that causality tests match. We use a probit model to analyze the extent to which the correlation between an energy type and total energy can predict the probability of a match. For the Toda-Yamamoto test the probit model can be formulated as:

$$P(M_c^{TY} = 1) = \Phi(\beta_0 + \beta_1 Cor_c) \tag{4}$$

where Φ is the cumulative distribution function of the standard normal distribution. In total, there are $c = 1, ..., 195$ (65 countries, each with 3 types of energy) comparisons of matches between an energy type-GDP causality test with a total energy-GDP causality test. A match of causality tests is denoted by $M_c = 1$.

$M_c = 0$ if the tests do not match. Cor_c denotes the correlation in first differences of a single type of energy with total energy for each c.

For the VECM/VARfd testing approach the effect of correlation between an energy type and total energy on the matching probability can be predicted by the model:

$$P(M_c^{VECM/VARfd} = 1) = \Phi(\beta_0 + \beta_1 Cor_c + \beta_2 VARfd_c) \tag{5}$$

where $VARfd_c = 1$ when a VAR in first differences was used for each c.

5. Results

5.1. Correlation Between Total Energy and Different Types of Energy

With only a few exceptions all types of energy are highly correlated with total energy consumption in each income group (Table 1). Petroleum products, in particular, has an exceptionally high correlation coefficient of at least 0.70 irrespective of the income group. The correlation coefficient for electricity is comparatively higher in high and middle income countries than in countries with lower income. For low and lower middle income countries we find a slightly higher correlation coefficient for renewables than in countries with higher income. Since, overall, the correlation coefficient differs only marginally between the income groups, we conclude that income is not decisive for the correlation of single types of energy with total energy.

Moreover, we find many indications that the correlation coefficient is not strongly influenced by the share of an energy type in total energy consumption. For example, although the share of petroleum products ranges from 0.13 in low income countries to 0.56 in high income countries, the correlation coefficient is almost the same in both cases. In low and lower middle income countries the correlation coefficients of petroleum products and renewables even seems to be negatively related to the share of the respective energy types.

5.2. Matching of Causality Tests

Comparing the probability for a match between energy-GDP and energy type-GDP causality tests (Table 2) with the reference values of 18.04%, shows that the test results do not match randomly. In fact, the reference values are clearly exceeded in all income groups. This result is also confirmed by the results for the causality test based on the VECM/VARfd model (Table 3).

Overall, we find a match of causality tests for 92 per cent of the countries for at least one energy type when summing up results from both the Toda-Yamamoto test and the VECM/VARfd testing approach (Table 4). For 82 per cent of the countries we find that at least two energy-type GDP tests match with the total energy-GDP test. For 43 per cent of the countries we find that all energy types yield exactly the same result as total energy. In addition, we find that, for the VECM/VARfd testing approach, the matching is considerably lower if either total energy or a single energy type is cointegrated with GDP.

Table 1: Correlation of different energy types with total energy consumption

Income group	Energy type	Corr. (avg.)	Cor. (Std. dev.)	Share early[1] (avg.)	Share late[2] (avg.)
All	Electricity	0.47	0.24	0.06	0.14
	Petroleum products	0.80	0.17	0.43	0.43
	Renewables	0.32	0.29	0.41	0.30
High	Electricity	0.61	0.21	0.10	0.21
	Petroleum products	0.87	0.09	0.56	0.52
	Renewables	0.18	0.18	0.09	0.06
Upper middle	Electricity	0.52	0.24	0.06	0.16
	Petroleum products	0.82	0.16	0.53	0.52
	Renewables	0.27	0.29	0.31	0.14
Lower middle	Electricity	0.38	0.19	0.04	0.09
	Petroleum products	0.77	0.19	0.33	0.36
	Renewables	0.44	0.32	0.60	0.48
Low	Electricity	0.27	0.25	0.02	0.05
	Petroleum products	0.70	0.22	0.13	0.17
	Renewables	0.42	0.24	0.80	0.72

[1] Share of energy type in total energy in the earliest available period in the dataset.
[2] Share of energy type in total energy in the latest available period in the dataset.

Table 2: Matching between energy-GDP and energy type-GDP Toda-Yamamoto causality tests (as % of all causality tests)[1]

Income group	Electricity			Petroleum Products			Renewables			Sample Size
	1%	5%	10%	1%	5%	10%	1%	5%	10%	
All	0.80	0.55	0.45	0.89	0.69	0.66	0.78	0.66	0.45	65
High	0.88	0.56	0.50	0.88	0.63	0.69	0.69	0.50	0.44	16
Upper Middle	0.67	0.57	0.52	0.86	0.76	0.62	0.76	0.67	0.48	21
Lower Middle	0.95	0.60	0.40	0.95	0.75	0.75	0.85	0.70	0.45	20
Low	0.63	0.38	0.25	0.88	0.50	0.50	0.88	0.88	0.38	8

[1] For the significance scenarios of $\alpha = 0.01$, $\alpha = 0.05$, and $\alpha = 0.1$.

Table 3: Matching between energy-GDP and energy type-GDP VECM/VARfd causality tests (as % of all causality tests)[1]

Income group	Electricity			Petroleum Products			Renewables			Sample Size
	1%	5%	10%	1%	5%	10%	1%	5%	10%	
All	0.58	0.45	0.43	0.80	0.60	0.49	0.78	0.49	0.38	65
High	0.38	0.31	0.44	0.69	0.63	0.50	0.75	0.38	0.38	16
Upper Middle	0.57	0.43	0.57	0.76	0.52	0.48	0.71	0.43	0.29	21
Lower Middle	0.75	0.65	0.45	0.90	0.65	0.50	0.85	0.55	0.45	20
Low	0.63	0.25	0.00	0.88	0.63	0.50	0.88	0.75	0.50	8

[1] For the significance scenarios of $\alpha = 0.01$, $\alpha = 0.05$, and $\alpha = 0.1$.

Table 4: Country overview of matches between energy-GDP and energy type-GDP causality tests

Income group	Country	Electricity		Petroleum Products		Renewables	
		Toda-Yamamoto	VECM/VARfd	Toda-Yamamoto	VECM/VARfd	Toda-Yamamoto	VECM/VARfd
High	Australia			X		X	
	Austria	X	X*	X	X*		X
	Canada	X		X	X	X	X
	Cyprus				X		
	Denmark				X		
	Finland	X	X*	X	X*	X	
	France	X				X	X
	Germany			X		X	
	Greece			X		X	X
	Hong Kong	X	X	X	X	X	X
	Hungary						
	Italy	X			X*		
	Portugal			X			
	Saudi Arabia	X	X*	X	X*		
	Sweden	X	X*	X	X*		
	United States	X			X	X	X
Upper Middle	Algeria	X		X	X*	X	
	Argentina						
	Brazil						
	Chile	X		X	X	X	X
	China	X	X			X	X
	Colombia	X	X	X	X	X	X
	Costa Rica			X	X	X	X

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Income group	Country	Electricity Toda-Yamamoto	Electricity VECM/VARfd	Petroleum Products Toda-Yamamoto	Petroleum Products VECM/VARfd	Renewables Toda-Yamamoto	Renewables VECM/VARfd
	Cuba	X	X	X			
	Dominican Republic	X	X	X	X	X	X
	Ecuador	X		X			
	Gabon						
	Iran			X			
	Jamaica			X	X	X	
	Jordan	X	X*	X	X*	X	
	Malaysia			X	X	X	X
	Mexico						
	Panama		X	X		X	
	South Africa	X	X	X	X	X	X
	Thailand	X	X	X	X	X	X
	Tunisia	X	X	X	X	X	X
	Turkey	X		X		X	
Lower Middle	Bolivia		X	X	X	X	X
	Cameroon	X	X	X	X	X	X
	Congo (Rep.)	X	X	X	X	X	X
	Cote d'Ivoire		X	X	X	X	
	Egypt		X				
	El Salvador	X	X*	X			
	Ghana	X			X		
	Guatemala	X				X	
	Honduras	X	X	X	X	X	X

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Income group	Country	Electricity		Petroleum Products		Renewables	
		Toda-Yamamoto	VECM/ VARfd	Toda-Yamamoto	VECM/ VARfd	Toda-Yamamoto	VECM/ VARfd
	India		X*			X	
	Indonesia	X	X	X	X	X	X
	Morocco			X	X	X	X
	Nicaragua			X	X	X	
	Nigeria	X	X	X		X	X
	Pakistan		X	X	X		
	Paraguay	X	X	X	X	X	X
	Philippines	X	X	X	X	X	X
	Senegal			X	X		X
	Sudan	X		X		X	
	Zambia		X				X
Low	Bangladesh	X		X		X	X
	Benin			X	X	X	X
	Congo (Dem. Rep.)			X	X	X	X
	Kenya					X	
	Myanmar		X		X		X
	Nepal	X	X	X	X	X	X
	Togo	X				X	X
	Zimbabwe				X	X	

Note: X represents a match between an energy-GDP and energy type-GDP causality test; *denotes cointegration

5.3. Explaining the Matching Probability

For the Toda-Yamamoto test we find a positive effect of correlation on matching. It is significant both in the 1% and 10% significance scenario, and almost significant in the 5% significance scenario (Table 5). We find a significantly negative constant in the 10% scenario. It, however, turns out to be insignificant in the 5% significance scenario and significantly positive in the 10% significance scenario. This means that,

Table 5: Probit estimation (dependent variable: matching probability)

	Toda-Yamamoto			VECM/VARfd		
	1%	5%	10%	1%	5%	10%
Constant	0.61^{***}	0.06	-0.49^{***}	-2.19^{***}	-1.43^{***}	-1.44^{***}
Cor	0.57^{*}	0.48	0.96^{***}	0.55	0.87^{***}	1.12^{***}
VAR				2.87^{***}	1.68^{***}	1.18^{***}
Log-Likelihood	–91.82	–128.11	–129.71	–78.33	–98.83	–110.34
Chi-Square	2.89	2.64	10.90	78.97	72.03	45.88
Observations	195	195	195	195	195	195

Note: ***,**,* denotes significance at the 1%, 5%, 10% level, respectively.

when reducing the nominal significance level, the probability of observing a match for a correlation of zero increases. The reason is that a reduction in the nominal significance level increases the probability of observing neutrality matchings. A nominal significance level of 1% should be the most adequate scenario, given that this testing procedure has inflated type 1 errors.

For the VECM/VARfd testing approach we find a significantly positive effect of correlation on matching both in the 5% and 10% significance scenario. The effect is almost significant in the 1% significance scenario. Here, $VARfd$ is a dummy variable to control for those cases where a VAR in first differences was applied. Accordingly, the constant describes the matching probability in those cases where the energy type is uncorrelated with total energy, and where either total energy or an energy type is cointegrated with GDP. It shows that, if one of the energy variables is cointegrated with GDP, the matching probability is very low.[7]

6. Discussion

Overall, we find systematic evidence for dependence of energy times series. With regard to $H1a$, in most cases, times series for different types of energy are highly correlated with total energy, widely irrespective of the energy types' share in total energy or the countries' development stage. Therefore, all country income groups are generally subject to the statistical issues we raise. The results of the matching analysis support our argument that, often, times series for different types of energy do not contain statistical information beyond total energy when using causality analysis. We derive this conclusion from the large number of cases where the results obtained from energy-GDP causality tests match with energy type-GDP tests. This supports $H1b$. Hence, when deriving energy policy implications from energy-type GDP causality tests, energy researchers need to address potential influences of other energy types. If, for example, petroleum products are found to cause GDP, it is required to discuss the influence of any other energy type, or total

[7]Note that correlation in first differences measures only linear dependence between changes of variables. The high constant values indicate that more kinds of statistical dependencies may be present than can be explained by linear dependence, e.g., non-linear relationships or relationships in levels other than cointegration.

energy. Concluding that economic growth is led by petroleum products (alone) might not fully answer the question of causality.

From our probit estimation we conclude that correlation has a positive effect on the probability that energy type-GDP tests match with total energy-GDP causality tests. For the majority of significance scenarios we therefore can confirm $H2$. The probit estimations show that the matching probability is particularly low if either the energy type or total energy is cointegrated with GDP.

Relating to our findings, the accuracy of an energy type-GDP causality test can be ensured in the following ways. First, those energy type causality tests which do not match with a total energy-GDP causality test might be a first starting point for assigning a specific role to single types of energy in the economy. At least, this would help to exclude that an energy type is only a good proxy for total energy. However, a bivariate analysis of energy type-GDP causality may be misleading since all energy types are likely to affect economic growth altogether. Accordingly, a multivariate framework with all energy types might be more appropriate than a bivariate one to also account for possible substitutability among energy types. Of course, this type of analysis needs to address the likely presence of multicollinearity. Finally, a conservative strategy would be to consider only those variables for energy-GDP analysis which share the same level of aggregation. This, however, would imply to analyze causality between total (or sectoral) energy and total (or sectoral) GDP alone.

7. Conclusion

This paper contributes to the debate on energy type-GDP causality by analyzing whether time series for single types of energy are sufficiently independent from total energy. If not, we argue, it is difficult to draw specific economic conclusions regarding single types of energy from causality analysis.

For a sample of 65 countries, we find that different types of energy are highly correlated with total energy consumption. Using the test by Toda and Yamamoto (1995) as well as a VECM/VARfd testing approach based on Engle and Granger (1987) for analyzing energy-GDP and energy type-GDP causality, we find matches of the results for 92 per cent of the countries for at least one energy type. Using a probit model we find that correlation between an energy type and total energy significantly increases the probability of a match.

Overall, implications for single types of energy may be more meaningful if energy types are sufficiently independent of total energy. This is more likely to be the case if one energy variable has a long-run relationship with GDP, hence is cointegrated, but the other is not. We conclude that more research is needed to better single out the economic relevance of single types of energy. A possible solution might be to consider more energy types than only one for the causality tests, in order to address the issue of omitted variable bias.

Technical Appendix

Calculation of Random Probability for Matches of Toda-Yamamoto Tests

The random probability of a match depends on the level and power of the Toda-Yamamoto test, as well as on the true data generating processes (DGP). In accordance with simulations by, e.g. Zapata and Rambaldi (1997), we assume the power of the Toda Yamamoto test for our sample size to be 85% (for a nominal significance level of 5%). Hence, the probability that the Toda-Yamamoto test detects causality, given that causality is indeed present in the true DGP, is 85%. Consequently, the probability of the Toda-Yamamoto test to infer non-causality, if causality is indeed present in the true DGP, is 15%. Furthermore, Zapata and Rambaldi (1997) have also shown that Toda-Yamamoto tests suffer from inflated type I errors, especially in small samples. Therefore, we assume the level of the TY test to be 10% for a nominal level of significance of 5%. Accordingly, the probability to detect causality, if no causality is present in the true DGP, is 10%. The probability to correctly reject causality, if no causality is present, is 90%. We calculate the probability of a random match of causality results for the Toda-Yamamoto test for all potential permutations of the true DGPs. The probabilities range from 1.63% to 18.04%. Hence, for the Toda-Yamamoto test we consider a percentage larger 18.04% as evidence of a match which is not merely random.

Calculation of Random Probability for Matches of VECM/VARfd Testing Approach

Calculating the reference scenario, were matches occur only randomly, is more complicated for the VECM/VARfd procedure. It requires information about the level and power of F-tests in VARs for pre-tested time series. In addition, the number of permutations of the true DGP increases strongly. However, introducing pre-tests for cointegration implies a reduction of random matching probabilities compared to the Toda-Yamamoto test. Hence, the probability with which causality matching for the VECM/VARfd procedure occurs is at most 18.04%.

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