



Munich Personal RePEc Archive

The electricity consumption versus economic growth of the Polish economy

Gurgul, Henryk and Lach, Lukasz

University of Science and Technology of Krakow AGH, University of
Science and Technology of Krakow AGH

1 December 2011

Online at <https://mpra.ub.uni-muenchen.de/35785/>

MPRA Paper No. 35785, posted 08 Jan 2012 00:00 UTC

The electricity consumption versus economic growth of the Polish economy*

Henryk Gurgul^{a,**} and Łukasz Lach^b

^a Department of Applications of Mathematics in Economics, Faculty of Management, AGH University of Science and Technology, Gramatyka 10 st., 30–067 Cracow, Poland, tel.: +48 012 6174310, fax: +48 012 6367005, e–mail: henryk.gurgul@gmail.com.

^b Department of Applications of Mathematics in Economics, Faculty of Management, AGH University of Science and Technology, Gramatyka 10 st., 30–067 Cracow, Poland, tel.: +48 012 6174218, fax: +48 012 6367005, e–mail: lukilach1983@o2.pl.

Abstract

The aim of this contribution is an investigation of causal interdependences between electricity consumption and GDP in Poland. Our research was conducted for total electricity consumption as well as for the industrial consumption of electricity. In order to reflect the causality between GDP and electricity consumption properly we performed our investigations in a three–dimensional framework with employment chosen as an additional variable. We used reliable quarterly data from the period Q1 2000 – Q4 2009. In order to check the stability of the causalities the investigations were performed on two samples: a full sample and a pre–crisis (i.e. Q1 2000 – Q3 2008) subsample. We applied both traditional methods as well as some recently developed econometric tools.

We found feedback between total electricity consumption and GDP as well as between total electricity consumption and employment. We also found unidirectional causality running from industrial electricity consumption to employment and no direct causal links between industrial electricity consumption and GDP. In addition, all these findings were, in general, not seriously affected by the financial and economic crisis of 2008. A significant exception is the causal effect of industrial electricity consumption on employment, which was more pronounced after the crisis of 2008.

Keywords: electricity consumption, economic growth, Granger causality.

JEL classification: C32, Q43.

* Forthcoming in *Energy Economics*.

** Corresponding author.

1. Introduction

Electricity has been the foundation of economic growth, and constitutes one of the most important infra-structural inputs in economic development. The growing interest in this area has largely been triggered by the growing demand for energy across the world, fuelled mainly by increasing economic activities across economies. A modern society implies growing reliance on networked information and communication technologies (ICTs), with more and more people using the Internet. Other ICTs such as cell phones, digital video recorders, digital music players, personal computers, and so on are quite common now. Therefore, companies, households and economies as a whole exhibit a demand for electricity. This demand is driven by such important factors as industrialization, extensive urbanization, population growth, and a rise in the standard of living.

In the past three decades, a number of studies have been performed in order to prove the interdependence between electricity consumption and economic growth. The findings show, in general, a strong relationship between electricity consumption and economic growth. However, the fact that there exists a strong relation between electricity usage and economic growth does not necessarily imply a causal dependence.

Moreover, some previous papers contain highly controversial results. This is why the previous literature that focused on the causal relationship between electricity consumption and economic growth was not able to provide general policy recommendations that could be applied across countries. Researchers indicate that many economists and policy makers were and still are concerned with the causal relationship between electricity consumption and economic growth because this relation has significant implications for governmental energy policy.

A major question is which variable should take precedence over the other, i.e. is electricity usage a stimulus for economic growth or does economic growth lead to an increase in electricity consumption? The answer to this question is the reason for categorization of published contributions concerning these relationships.

The main stream of literature concerning the causal relationship between electricity consumption and GDP growth can be divided into four groups. They are of great importance for electricity policy.

First, unidirectional causality running from electricity usage to GDP growth implies that restrictions on electricity may hamper economic growth while increases in electricity usage may contribute to economic growth. In the last years ecologists have increased pressure on governments to reduce carbon dioxide emissions in order to slow down the rate of climate

change, and this pressure has especially intensified on developing countries. On the other hand, emerging economies worry about the negative impact on economic growth caused by the restricted consumption of fossil fuels, which are the main sources of electricity generation.

Second, unidirectional causality running from GDP growth to electricity usage could mean that electricity usage conservation policies may be justified with little or no negative repercussions on economic growth. This effect means that such an economy can be numbered among those which are non dependent on energy. In addition, a continuous increase in GDP may imply a permanent increase in electricity consumption.

Third, feedback (i.e. a bidirectional causal relationship between electricity usage and GDP growth) means that electricity consumption and economic growth are mutually affected and jointly determined at the same time. If bidirectional causality is found, economic growth may demand more electricity whereas more electricity consumption may induce economic growth.

Finally, a fourth (but less probable) scenario of lack of any causal relationship means that there is no interdependence between electricity consumption and GDP growth, so that neither expansive nor conservational policies with respect to electricity consumption have any effect on GDP growth.

The organization of the study is as follows. In the next section we give a literature overview. In the third section the main conjectures of the paper are formulated. The fourth section describes the dataset. In the fifth section the econometric methodology is explained. Section 6 contains empirical results. Section 7 concludes the paper.

2. Literature overview

The subject of the causal relationship between various forms of energy consumption and GDP growth has been well–documented in the econometric energy literature. The bulk of this literature focuses on developed countries. Different contributions have focused on different countries, time periods, and have used different proxy variables for energy usage. The empirical outcomes of these contributions are not in line with each other and often just controversial. The findings differ even on the direction of both linear and nonlinear causality and its long–term versus short–term influence on energy policy. The type or lack of causal relationship has policy implications. In the next paragraphs we will review some of previous studies related to the causal links between economic growth and electricity usage.

Electricity has become the preferred and dominant form of energy in the expanding areas of economic activity in industrial economies. It has been a major factor in the improvement of the standard of living and has played a crucial role in technological and scientific progress. Therefore, this kind of energy is commonly thought to be especially important also for economic growth.

Ferguson et al. (2000) have studied the interdependences between electricity usage and economic growth in over 100 countries, and found that, as a whole, there is a strong correlation between these variables. Shiu and Lam (2004) investigated the relationship between electricity consumption and GDP growth for the Chinese economy using data for the 1971–2000 period. The authors found short–run unidirectional causality running from electricity consumption to economic growth. This implies that an increase in electricity consumption supported economic growth in China in the period under study. Later investigations by Yuan et al. (2007) performed for the period 1978–2004 are in line with contribution by Shiu and Lam (2004). Yang (2000) has found a bidirectional causal relationship between GDP and electricity consumption in Taiwan. Morimoto and Hope (2004) applied Yang’s model to examine the impact of electricity supply on economic growth in Sri Lanka and found similar results. Jumbe (2004) showed that the Granger causality between GDP and electricity consumption for Malawian time series data over the period 1970–1999 runs in both directions (feedback). The error correction model, however, indicated only a unidirectional long–run relationship running from GDP to electricity consumption. Yoo (2005) performed an analogous analysis for Korea over the period 1970–2002 and found a short–run unidirectional causal relationship running from electricity consumption to GDP growth. Altinay and Karagol (2005) demonstrated that electricity consumption was a leading indicator of the economic growth of Turkey. Halicioglu (2007) in a more recent study for the period 1968–2005 demonstrated long–run causality running from income to electricity consumption in Turkey. However, in the short–run the results were inconclusive.

In contrast to the latest contributions, Narayan and Smyth (2005) established over the period 1966–1999 that real income Granger caused electricity consumption in Australia. On the other hand, Narayan and Singh (2007) in their contribution on Fiji found that in the long–run causality runs from electricity consumption and labour force to GDP, implying that Fiji is an energy–dependent country and thus energy conservation policies may have an adverse effect on Fiji’s economic growth. Moreover, Narayan et al. (2008), Narayan and Smyth (2008) investigated interdependencies between electricity consumption and GDP for G7

countries (the largest economies in the world). The authors found that except for the USA, electricity consumption has a statistically significant positive effect on real GDP in the short-run. This finding implies that except for the USA, electricity conservation policies will hurt real GDP in the G7 countries. Ghosh (2009) found unidirectional short-run causality running from economic growth to electricity supply in India. He concluded that the absence of causality in the opposite direction implies that electricity demand and supply side measures can be adopted to reduce the wastage of electricity, which should not affect the future economic growth of India.

In a more extensive study Yoo (2006) tested Granger causality among real GDP and electricity consumption for four Asian countries: Indonesia, Malaysia, Singapore, and Thailand, over the period 1971–2002. The causality tests indicated a strong feedback relationship between electricity consumption and economic growth for Malaysia and Singapore. Causality running from economic growth to electricity consumption was reported for Indonesia and Thailand. This result means that energy conservation policies cannot dampen the economic growth of these two countries. To summarize, in all the four countries economic growth was found to stimulate electricity consumption. In a recent study performed on a group of countries Yoo and Lee (2010) found that both per-capita and total electricity consumption are expected to continuously increase for many years. Moreover, the authors expected that an increase in electricity consumption should be stimulated by growth in per-capita income.

In a recent study Wolde-Rufael (2006) applied a Toda–Yamamoto–based causality approach to test for dynamic dependences between electricity consumption and GDP for 17 African countries over the period 1971–2001. In general, results varied from country to country. However, all four possible relations mentioned in the introduction were detected. Squalli (2007) received similar range of causalities between electricity consumption and economic growth for 11 OPEC countries using time series data over the period 1980–2003.

Chen et al. (2007) tested causality for 10 Asian countries (China, Hong Kong, India, Indonesia, Korea, Malaysia, the Philippines, Singapore, Taiwan, and Thailand). The authors used panel causality tests based on the error correction model over the period 1971–2001. They found (except for China, Taiwan and Thailand) a unidirectional short-run causality running from economic growth to electricity consumption, and a feedback in the long-run. In a study from 2007 Mozumder and Marathe confirmed a unidirectional causality running from per capita GDP growth to per capita electricity consumption in Bangladesh over the period 1971–1999.

Lee and Chang (2008) examined 16 Asian countries and found that in general reducing energy consumption does not adversely affect GDP in the short-run but it does in the long-run. Thus, these countries should adopt a more vigorous energy policy.

In general, the bootstrap approach has been rarely used in previous energy literature. This approach is especially useful when analyzing small samples for which the application of the asymptotic theory of a traditional Granger causality test may lead to spurious results. Thus, the bootstrap approach used by Narayan and Prasad (2008) in their paper was likely to produce more efficient results compared with asymptotic-based tests for causality. They found evidence in favour of electricity consumption causing real GDP in the long-run in Australia, Iceland, Italy, the Slovak Republic, the Czech Republic, Korea, Portugal, and the UK. The implication is that electricity conservation policies may negatively impact real GDP in these countries. However, for the rest of the countries (approximately 73 percent of the OECD countries) their findings suggested that electricity conservation policies should not affect real GDP.

The first study in the energy economics literature that investigates causality between electricity consumption and economic growth for a large group of transition countries is the one by Acaravci and Ozturk (2010). The goal of these authors was to examine whether there is any long-run relationship and causality between electricity consumption and economic growth for 15 European transition economies. By using Pedroni's panel cointegration tests (see Pedroni, 1999, 2004) for the period 1990–2006 they did not confirm long-term equilibrium relationship between electricity consumption per capita and the real GDP per capita. From this study it follows that electricity consumption policies have no effect on the level of real output in the long-run for these countries. The authors also conclude that the literature reports conflicting results and there is no consensus neither on the existence nor the direction of causality between electricity consumption and economic growth. However, they stress that the findings of their study have important policy implications for energy economics and show that this issue still deserves considerable attention.

In their later contribution, Ozturk and Acaravci (2011) applied the ARDL bounds cointegration approach to investigate the causal relationship between electricity consumption and economic growth for eleven Middle Eastern and North African (MENA) countries over the period 1990–2006. The authors found no clear evidence of a long-run equilibrium relationship between electricity consumption and economic growth in Iran, Morocco and Syria. Therefore, these countries were eliminated from the sample. However, they detected relationships in the levels of electricity consumption and economic growth for Egypt, Israel,

Oman and Saudi Arabia. Their test of causality showed unidirectional short-run Granger causality running from economic growth to electricity consumption in Israel. In the cases of Egypt, Oman, and Saudi Arabia, the causality test revealed the existence of unidirectional short- and long-run Granger causality from electricity consumption to economic growth. The authors concluded that their results provided some evidence on the long-run causal relationship between electricity consumption and economic growth in MENA countries.

The study by Payne (2010) discusses the various hypotheses associated with the causal relationship between electricity consumption and economic growth and provides a survey of the empirical literature. The latter focused on country coverage, variables selected, model specification, econometric approaches and empirical results. In general, the results for the specific countries and time periods were a bit surprising, since they showed that in around 31.15% of all cases the neutrality hypothesis (i.e. no causality in any direction) was supported; in 27.87% – the conservation hypothesis (growth causes electricity consumption) held; in 22.95% – the growth hypothesis (electricity usage causes growth) and in 18.03% the feedback hypothesis (bidirectional causality) was found to be valid. It follows from these numbers that in 45.90% cases (27.87% + 18.03%) economic growth was found to have an impact on the amount of electricity usage and in 40.98% cases (22.95% + 18.03%) reverse causality was found.

Ozturk (2010) provided an extensive survey of the recent contributions in the literature of the energy consumption–economic growth and the electricity consumption–economic growth causality nexuses. The survey is mostly concerned with empirical studies, which focus on either testing the role of electricity in stimulating economic growth or examining the direction of causality between these two variables. The author classified the various studies into country-specific and multi-country studies on energy (electricity) consumption and economic growth. Although he does not neglect the importance of energy (including electricity) for every economy, there are some methodological reservations about the results from these empirical studies. A general conclusion drawn by the author of the discussed survey was that the literature has developed conflicting results, i.e. the results obtained from the multi-country studies and country-specific studies on the causality between the variables under examination led to contradictory conclusions. Moreover, there was no consensus either on the existence or on the direction of causality between electricity consumption and economic growth. According to Ozturk, in order to overcome these problems and achieve consensus, researchers should use the autoregressive distributed lags (ARDL) bounds test, two-regime threshold cointegration models, panel data approach and multivariate models

including additional variables (such as: real gross fixed capital formation, labor force, carbon dioxide emissions, population, exchange rates, interest rates, etc.). Thus, researchers should focus more on recent methods and perspectives rather than employing well-known traditional approaches based on a set of common variables for different countries and different intervals of time.

A comprehensive overview of results published in the literature is also given in Yoo and Kwak (2010). Besides presenting a survey of the recent literature, this paper examines causal links between economic growth and electricity usage in seven South American countries. The results indicated that the causal nexus between the variables under examination varies across the examined countries.

To summarize, a considerable fraction of recent contributions have detected an interrelation between electricity consumption and economic growth. Therefore, we may expect that, in general, the usage of electricity may be a limiting factor in economic growth and that shocks to the electricity supply can have significant repercussions on economic growth.

In light of the literature overview presented above one can easily see that not much attention was paid to the fast growing Central and Eastern European transition economies with respect to the interrelation between economic growth and electricity consumption. Up to now and to the best of our knowledge there is no extensive study about links between growth and electricity consumption for the largest EU member currently in transition – Poland. Recognition of electricity usage–economic growth links is very important for countries in transition, especially in the context of the EU Emission Trading System (EU ETS) started in 2005, which has launched the world’s biggest experiment in the use of a “cap and trade” scheme for reducing greenhouse gas emissions. The Central and Eastern Europe economies produce electricity mainly on the basis of traditional fuels like coal. Therefore, the EU objective to shift its members to low–carbon economies may turn out to be very costly, especially in the case of Poland. This is the reason why Poland and some other EU members disapprove of a quick shift to a clean energy economy, because this would be expected to slow down their economic growth. It therefore seems fully justified to examine in particular whether the economic growth in Poland depends on the level of electricity consumption.

Answering this question is crucial not only for the Polish energy policy but also for the energy policies of other EU members in the context of the EU goal of a substantial reduction of greenhouse gas emissions.

3. The main research hypotheses

The direction of causality between electricity consumption and economic growth in the light of the literature overview is not consistent and depends on different data sets, the characteristics of different countries and the different econometric methodologies applied. As we have already mentioned in previous sections, the prevailing point of view in the literature is that electricity consumption is a source of economic growth (growth hypothesis). However, for many countries the opposite direction of causality (conservation hypothesis) or even feedback (feedback hypothesis) was reported. A neutrality hypothesis (no causality in any direction) can also be found in considerable number of papers.

One of the main factors determining GDP is employment. In order to take this fact into account and avoid biased results of causality analysis involving electricity consumption and GDP we also included employment in our causality investigations.¹

Taking into account results concerning other countries from Central and Eastern Europe, and the dominant role of electricity in Polish energy balance one may expect that the following hypothesis might hold true for Poland:

Conjecture 1: There was feedback between total electricity consumption and GDP as well as between total electricity consumption and employment in Poland in the years 2000–2009 (i.e. the feedback hypothesis held true).

An interesting question arises as to the stability of this feedback after the world economic crisis which began in 2008. Poland was the only European country with a positive rate of GDP growth in 2008. Therefore, in line with Conjecture 1, one might assume the stability of the feedback between total electricity consumption and GDP as well as between total electricity consumption and employment. Therefore our next hypothesis is of the form:

Conjecture 2: Feedback between total electricity consumption and GDP as well as between total electricity consumption and employment in Poland was robust in the face of the financial and economic crisis of 2008.

Electricity is consumed by industries and by households. In recent decades there was no rise in the industrial usage of electricity in Poland conditional on technical progress. However, the usage of electricity by households (services sector) has been continuously increasing. Therefore, we may formulate the following:

¹ Employment was often used in previous papers related to energy–GDP links (e.g. Chang et al., 2001).

Conjecture 3: *In years 2000–2009 the interdependencies between industrial energy consumption, GDP and employment in Poland were not so strongly pronounced as in the case of total electricity consumption.*

The impact of the economic crisis of 2008 on the nature of the dynamic links between the usage of electricity in industry and GDP is also worth investigating. Taking into account the suspicions reflected in Conjecture 2, one may also formulate:

Conjecture 4: *The crisis of 2008 had no impact on the structure of causal dependences between industrial energy consumption, GDP and employment in Poland.*

The above conjectures will be tested by different causality tests. A detailed description of these methods will be presented in section 5. In the next section we will first characterize the time series included in our sample.

4. The dataset and its properties

In the first part of this section we will present the applied dataset. Next, we will check the stationarity properties of all the time series. The identification of the orders of integration of all time series is a crucial stage of causality analysis.

4.1. Description of the dataset

The chosen dataset includes quarterly data on GDP, total electricity consumption, industrial electricity consumption and employment in Poland in the period Q1 2000 – Q4 2009. Our dataset contains 40 observations. In order to avoid spurious results of further causality analysis we conducted several transformations of our dataset. Firstly, in order to remove the impact of inflation we calculated GDP at constant prices (year 2000). Secondly, since each variable used was characterized by significant quarterly seasonality, the X-12 ARIMA procedure (which is currently used by the U.S. Census Bureau for seasonal adjustment) of Gretl software was applied to adjust each variable. Finally, we transformed each seasonally adjusted variable into logarithmic form, since this operation (as one of the Box-Cox transformations) may stabilize variance and therefore improve the statistical properties of the data, which is especially important for parametric tests. Table 1 contains some initial information:

INSERT TABLE 1 AROUND HERE

One important point that distinguishes our paper from other contributions on electricity consumption and economic growth is that we applied less aggregated quarterly data. This is because the data necessary covered only the recent few years and thus a causality analysis based on annual data could not have been carried out due to lack of degrees of freedom.² Moreover, the application of lower frequency data (e.g. annual) may seriously distort the results of Granger causality analysis because some important interactions may stay hidden (for more details see e.g. Granger et al., 2000).

The originality of this paper is also related to another important fact. The methodology for conducting causality analysis does not allow an exploration of the dynamic links between Poland's GDP, electricity consumption and employment in the period after the bankruptcy of Lehman Brothers Bank (due to insufficient sample size), so we decided to use an alternative approach to examine the impact of the economic crisis of 2008 on the structure of the dynamic links between variables. That is, apart from the full sample, we additionally decided to examine the pre-crisis period (i.e. Q1 2000 – Q3 2008). It seems reasonable to expect this approach to be helpful in identifying the impact of the financial crisis on GDP–electricity usage relationships through the specification of differences in the structures of causal links between the variables for both samples under study. However, this method has a relatively serious drawback as the power properties of causality tests strongly depend on sample size.

The preliminary part of our analysis contains some descriptive statistics of all the variables. The following table contains suitable results. The results obtained for the pre-crisis subsample are presented in square brackets:

INSERT TABLE 2 AROUND HERE

In order to conduct a comprehensive initial analysis one should also make use of charts generated for all the variables under study. The following figure contains plots of seasonally adjusted and logarithmically transformed variables:

INSERT FIGURE 1 AROUND HERE

In the period under study there was a relatively stable development of the Polish economy as *GDP* exhibited an upward tendency. The Polish economy was one of the few that managed to avoid undesirable consequences of the crisis of September 2008. However, after the third

² The lack of reliable datasets of sufficient size is a common characteristic of most of post-Soviet economies.

quarter of 2008 one could observe slight slowdown of the rate of development of the Polish economy. For *EMPL* in this period there was a stable rise between 2003 and 2008. However, before 2003 and after the crisis of September 2008 slight drops were also observed. It is also interesting to note that before the beginning of the world economic crisis the *ELC_{TOT}* exhibited a significant upward tendency while *ELC_{IND}* did not exhibit any type of time trend. Finally, we should note that figure 1 clearly shows the significant reaction of all examined variables to economic crisis of September 2008, which justifies the need to examine the impact of this shock on the structure of causal dependences between the variables. The descriptive analysis of the time series included in our dataset will be extended in the next subsection by stationarity testing, which is a crucial stage of causality analysis.

4.2. Stationarity properties of the dataset

First, we conducted an Augmented Dickey–Fuller (ADF) unit root test. Before conducting the test, we set up a maximal lag length equal to 6 and then we used information criteria (namely, the AIC, BIC and HQ) to choose an optimal lag length from the set $\{0, 1, \dots, 6\}$. However, the results of an ADF test are relatively sensitive to any incorrect establishment of lag parameter. Moreover, this test tends to under–reject the null hypothesis pointing at nonstationarity too often (low power against stationary alternatives has been frequently reported by many authors, see e.g. Agiakoglu and Newbold, 1992). Therefore, to confirm the results of the ADF test a Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test was also conducted. Note that in contrast to the ADF test the null hypothesis of a KPSS test refers to the stationarity of time series.

Since it is possible that two unit root tests lead to relatively different conclusions, we used a third test to make a final decision about stationarity. In this paper we applied the Phillips–Perron (PP) test, which is based on a nonparametric method of controlling for serial correlation when testing for a unit root. As with ADF the null hypothesis refers to nonstationarity.

The following table contains the results of the stationarity analysis. The results obtained for the pre–crisis subsample are once again presented in square brackets. Bold face indicates finding nonstationarity at a 5% level:

INSERT TABLE 3 AROUND HERE

An analysis of the outcomes presented in table 3 shows that only ELC_{IND} was found to be a stationary process with constant mean at a 5% level (it was confirmed by two of three conducted tests) while all other time series were found to be nonstationary (in some cases it also was confirmed by two of the three tests). Both these findings were obtained for the full sample and the pre-crisis subsample. Some further calculations (conducted for first differences) confirmed that all nonstationary variables are I(1) regardless of sample size.³

5. Methodology

In this paper we applied both linear and nonlinear Granger causality tests to explore the dynamic relationships between GDP and electricity consumption in Poland. The methodology of our research was a mixture of a traditional approach and some recent developments in econometric methods of analysing causal links. In general our research was conducted in two three-dimensional variants, each of which involved GDP , $EMPL$ and one electricity-related variable (ELC_{TOT} or ELC_{IND}).

5.1. Linear short- and long-run Granger causality tests

Since the idea of Granger (1969) causality is well known and has been widely used in previous studies we will not explain it in detail. By and large, this concept is used to investigate whether a knowledge of the past and current values of one stationary variable is helpful in predicting the future values of another one or not. If the time series under study are nonstationary then the outcomes of typical linear causality tests may lead to misleading conclusions, which has been shown in previous empirical (Granger and Newbold, 1974) and theoretical (Phillips, 1986) deliberations. Since all but one examined variable were found to be I(1) we applied three econometric methods suitable for testing for linear short- and long-run Granger causality in this context, namely, a traditional analysis of the vector error correction model (VECM), the sequential elimination of insignificant variables in VECM and the Toda-Yamamoto method.

If variables are integrated in the same order one may perform a cointegration analysis. The existence of cointegration implies long-run Granger causality in at least one direction (Granger, 1988). The direction of this causality may be examined through an estimation of a suitable VEC model and a test (using t -test) of the statistical significance of the error

³ We would like to underline that detailed results of all computations which are not presented in the text (usually to save space) in detailed form are available from authors upon request.

correction terms. Checking joint significance (using F -test) of lagged differences allows for short-run causality testing in a VEC framework. The application of an unrestricted VEC model has got some drawbacks, however. In practical research it is often necessary to consider a relatively large number of lags in order to avoid the problem of the autocorrelation of residuals. On the other hand, a large number of lags may significantly reduce the number of degrees of freedom, which in turn has an undesirable impact on test performance, especially for small samples. Thus, a sequential elimination of insignificant variables was additionally applied for each VECM equation separately to test for short- and long-run Granger causality. At each step the variable with the highest p -value (t -test) was omitted until all remaining variables have a p -value no greater than a fixed value (in this paper it was 0.10). More technical details of this approach may be found in Gurgul and Lach (2010).

The Toda–Yamamoto (1995) approach for testing for Granger causality has been commonly applied in recent empirical studies (see e.g. Keho, 2007) since it is relatively simple to perform and free of complicated pretesting procedures, which may bias the test results, especially when dealing with nonstationary variables. The most important feature of this concept is the fact that the Toda–Yamamoto (TY) testing method is applicable even if variables are characterized by different orders of integration (which is true in the case of ELC_{IND}). As we have already mentioned, in such cases a standard linear causality analysis cannot be performed by the direct application of a traditional vector autoregression (VAR) or VEC model. On the other hand, differencing or calculating the growth rates of some variables allows the use of the traditional approach, but it may also cause a loss of long-run information and lead to problems with the interpretation of test results.

Since the TY methodology is also well known we will only provide a brief description (for a comprehensive description see e.g. Toda and Yamamoto, 1995). In order to use this procedure one should assume that the order (denote this lag parameter p_1) of the VAR model is known. If not, it should be established by means of some standard statistical methods (e.g. the application of a consistent model selection criterion etc., for details see Paulsen, 1984). Next, one should establish the highest order of integration of all variables (denote this parameter p_2). According to Toda and Yamamoto (1995) parameter p_2 is an unrestricted variable since its role is to guarantee the use of asymptotic theory. Finally, after the estimation of an augmented $VAR(p_1+p_2)$ model one should apply a standard Wald test to check the statistical significance of the first p_1 lags obtained from an augmented model. If some specific modeling assumptions (e.g. whiteness of error term etc., for more details see

Lütkepohl, 1993) hold true then the TY test statistic is asymptotically $\chi^2(p_1)$ distributed. Since we dealt with relatively small samples we applied the TY test statistic in its asymptotically F -distributed variant, which performs better for small samples (for more details see e.g. Lütkepohl, 1993).

All three linear methods described above have several drawbacks, which are typical of parametric tests. Firstly, the application of asymptotic theory may lead to spurious results if suitable modeling assumptions do not hold. Secondly, even if all modeling assumptions are generally fulfilled, the distribution of the test statistic may still be significantly different from an asymptotic pattern when dealing with extremely small samples. One possible way of overcoming these difficulties is the application of the bootstrap technique. This method is used for estimating the distribution of a test statistic by resampling data. Since the estimated distribution depends only on the available dataset, it may be reasonable to expect that the bootstrap approach does not require such strong assumptions as parametric methods. However, bootstrap methods cannot be treated as perfect tools for solving all possible model specification problems. This approach is likely to fail in some specific cases and therefore should not be used without second thought (see e.g. Horowitz, 1995).

In this paper we applied a bootstrap based on leveraged residuals.⁴ In recent years the academic discussion on the establishment of the number of bootstrap replications has attracted considerable attention (see e.g. Horowitz, 1995; Lach, 2010). In our research we applied the recently developed procedure of establishing the number of bootstrap replications presented by Andrews and Buchinsky (2000). In all cases our goal was to choose such a value of number of replications which would ensure that the relative error of establishing the critical value (at a 10% significance level) would not exceed 5% with a probability equal to 0.95. The Gretl script including all mentioned linear methods with asymptotic- and bootstrap-based variants is available from the authors upon request.

5.2. Nonlinear Granger causality test

Generally, the motivation to use nonlinear methods in testing for causality is twofold. Firstly, the traditional linear Granger causality test has been found to have extremely low power in detecting certain kinds of nonlinear causal relationships (see e.g. Brock, 1991; Gurgul and Lach, 2009). Secondly, since linear methods depend on testing the significance of suitable

⁴ The technical details of resampling procedure applied in our bootstrap research may be found in Hacker and Hatemi (2006).

parameters only in a mean equation, causality in any higher-order structure (like causality in variance etc.) cannot be explored (Diks and DeGoede, 2001).

In this paper the nonlinear causality test proposed by Diks and Panchenko (2006) was applied. We decided to use some typical values of the technical parameters of this method, which have been commonly used in previous papers (e.g. Diks and Panchenko, 2005, 2006; Hiemstra and Jones, 1994; Gurgul and Lach, 2010). The bandwidth (denoted as b_{DP}) was set at a level of 0.5, 1 and 1.5 while the common lag parameter (denoted as l_{DP}) was set at the order of 1 and 2. A detailed description of the role of these technical parameters and the form of test statistic may be found in Diks and Panchenko (2006).

Since the results of various heteroscedasticity tests provided no significant proof of the presence of heteroscedasticity we did not re-run the nonlinear causality analysis for filtered time series. As stated in Diks and Panchenko (2006), using a conditional heteroscedasticity filter may affect the dependence structure and consequently the power of the test. Moreover, without knowledge about the true functional form of the process, a simple conditional heteroscedasticity filter (like an ARCH or a GARCH model) may not entirely remove the conditional heteroscedasticity in the residuals.⁵

6. Empirical results

In this section we present the results of short- and long-run linear Granger causality tests as well as the outcomes of nonlinear causality analysis. Our goal was to examine the nature of the dynamic links between electricity consumption and GDP in Poland in the periods Q1 2000 – Q4 2009 (full sample) and Q1 2000 – Q3 2008 (pre-crisis subsample). As we have already mentioned, our research was performed in a three-dimensional framework, as fluctuations of employment may have a significant impact on the structure of electricity usage-GDP links. We examined two sets of variables, each of which contained GDP, employment and one electricity-related variable.

6.1. Total electricity consumption and GDP

Since ELC_{TOT} , GDP and $EMPL$ were all found to be $I(1)$ we first performed a cointegration analysis. The type of deterministic trend was specified using the possibilities listed in Johansen (1995). Taking into account the results presented in subsection 4.2 (no trend-

⁵ We applied Diks and Panchenko's (2006) nonlinear procedure using all practical suggestions presented in Gurgul and Lach (2010).

stationarity) we assumed the third case, i.e. the presence of a constant in both the cointegrating equation and the test VAR. Next, we used information criteria (i.e. AIC, BIC, HQ) to establish the appropriate number of lags.⁶ The final lag length was established at a level of 5. It should be noted that the same lag parameter was found to be the most suitable for the pre-crisis subsample. The results of Johansen cointegration tests are presented in the following table (once again results referring to the reduced sample are presented in square brackets):

INSERT TABLE 4 AROUND HERE

As we can see both variants of Johansen test (i.e. Trace and Maximal Eigenvalue) provided solid evidence for claiming that for both samples the dimension of cointegration space was equal to two (at 10% level). Next, we estimated suitable VEC models using the full sample and the pre-crisis subsample. In both cases we assumed 4 lags (for first differences) and two cointegrating vectors.⁷ The following table contains p -values obtained while testing for linear short- and long-run Granger causality using unrestricted VEC models and the sequential elimination of insignificant variables (p -values referring to the reduced sample are presented in square brackets, bold face indicates finding a causal link in a given direction at a 10% level):

INSERT TABLE 5 AROUND HERE

The results obtained for the unrestricted VEC model provided a basis for claiming that ELC_{TOT} Granger caused GDP in the short-run in the period Q1 2000 – Q4 2009 (this was confirmed only by a bootstrap-based test). On the other hand, the sequential elimination of insignificant variables led to the conclusion that in the short-run there was feedback between these variables (which was confirmed by asymptotic- and bootstrap-based test). Moreover, the analysis of pre-crisis subsample led to similar results.

Despite the sample, and the type of critical values used we found unidirectional short-run linear causality running from employment to total electricity consumption. On the other hand the structure of short – run causal links between GDP and $EMPL$ was found to be influenced by the analyzed period and testing method used.

⁶The maximal lag length (for levels) was set at a level of 6. BIC pointed at one lag, but the results of Ljung-Box Q-test confirmed that in the case of one lag residuals were significantly autocorrelated, which in turn may seriously distort the results of the causality analysis.

⁷ The first vector (denoted as EC_1) involved GDP and ELC_{TOT} while the second one (EC_2) involved $EMPL$ and ELC_{TOT} .

In all the research variants the EC_1 component was found to be significant in GDP and ELC_{TOT} equations, which provides a basis for claiming that for total electricity consumption and output there was feedback also in the long-run. Furthermore, the sequential elimination indicated the existence of feedback between ELC_{TOT} and $EMPL$ and unidirectional causality from GDP to $EMPL$ in the long-run.

In general, the results for the pre-crisis subsample led to a conclusion similar to the analysis of the full sample. We should just mention that before the crisis the impact of $EMPL$ on GDP (short-run) and ELC_{TOT} (long-run) was rather weak (it was not confirmed during an analysis of the unrestricted VEC model). On the other hand, long-run causality from GDP and total electricity consumption to employment was found to be stronger before September 2008.

For the sake of comprehensiveness we additionally applied a Toda-Yamamoto approach for testing for causal effects between ELC_{TOT} , GDP and $EMPL$. Cointegration methodology was not applicable to ELC_{IND} , GDP and $EMPL$, thus the differences in structures of linear causal links between GDP and ELC_{TOT} as well as between GDP and ELC_{IND} could be compared only on the basis of the TY approach.

The following table contains p -values obtained while testing for linear short-run Granger causality between ELC_{TOT} , GDP and $EMPL$ using the Toda-Yamamoto approach. It seems interesting to see if the results of the TY approach are in line (at least to some extent) with outcomes obtained after an analysis of the VEC model (in unrestricted and sequentially-eliminated variants), which is especially important in terms of the robustness and validation of the empirical results. Whenever test results indicated the existence of a causal link in a given direction (at 10% level) bold face was used to mark this finding. Results referring to the reduced sample are presented in square brackets:

INSERT TABLE 6 AROUND HERE

As we can see, before the crisis of September 2008 GDP was found to Granger cause total electricity consumption. This result was obtained only by the bootstrap-based TY procedure. There were no other linear causal links significant at a 10% level for the pre-crisis subsample. However, when the full sample was considered the causalities from GDP and $EMPL$ to ELC_{TOT} were found to be significant at a 10% level in asymptotic- and bootstrap-based variants.

Finally, a nonlinear causality analysis was performed for the residuals resulting from all linear models, i.e. the residuals of unrestricted VECM, the residuals resulting from individually (sequentially) restricted equations and the residuals resulting from the augmented VAR model applied in the Toda–Yamamoto method.⁸ In all cases no significant evidence of heteroscedasticity was found, therefore no filtering was applied. Since for the residuals of the unrestricted VECM and the residuals resulting from individually (sequentially) restricted equations no significant (at a 10% level) nonlinear links were found, we did not find a reason to present these results in separate tables.

However, some statistically significant nonlinear relations were found for the residuals of the augmented VAR applied in the TY method. The following table presents p -values obtained while testing for nonlinear Granger causality between ELC_{TOT} , GDP and $EMPL$ (bold face was used to mark finding causality at a 10% level, p -values referring to the reduced sample are once again presented in square brackets):

INSERT TABLE 7 AROUND HERE

This time the results obtained for the two samples were relatively different. Before the crisis one could observe feedback between GDP and ELC_{TOT} and unidirectional causality from $EMPL$ to ELC_{TOT} . On the other hand causality from ELC_{TOT} to GDP and $EMPL$ was found to be statistically significant for the full sample.

In general, the results of all the methods provided relatively strong support for claiming that for total electricity consumption and GDP as well as for ELC_{TOT} and employment Granger causality runs in both directions. This result was found for both periods. Moreover, it is worth noting that this conclusion, in general, was confirmed by the results of two completely different methods, namely a two-stage analysis of the VEC model and the TY approach (with a post-TY nonlinear test), which somewhat confirms the robustness of this major conclusion when exposed to the statistical tools. Therefore, we found strong support for claiming that Conjecture 1 and Conjecture 2 are both true.

6.2. Industrial electricity consumption and GDP

Since ELC_{IND} was found to be stationary (in both periods) a cointegration analysis could not be carried out for the ELC_{IND} , GDP and $EMPL$ variables. In this case the Toda–Yamamoto

⁸ Residuals are believed to reflect strict nonlinear dependencies since the structure of linear connections had been filtered out after an analysis of linear models (Baek and Brock, 1992).

procedure was the only applicable method for testing for linear Granger causality in a three-dimensional framework. Therefore, the differences in the structures of linear causal links between economic growth and both electricity-related variables could be compared only on the basis of this approach. The optimal lag length for the unrestricted VAR model was once again set at the level of five (for both samples). The following table contains p -values obtained while testing for linear short-run Granger causality using the Toda-Yamamoto approach. Whenever test results indicated the existence of a causal link in a given direction (at a 10% level) bold face was used to mark this finding. The results referring to the reduced sample are presented in square brackets:

INSERT TABLE 8 AROUND HERE

Regardless of the type of critical values used no causal links were found for the pre-crisis subsample. On the other hand, causality from ELC_{IND} to employment was found to be statistically significant for the full sample. This result may be interpreted as proof of the fact that during the period of economic crisis industrial electricity consumption had an extremely significant impact on employment in Poland.

A nonlinear causality analysis was also performed for the residuals resulting from the augmented VAR model applied in the Toda-Yamamoto method. No significant evidence of heteroscedasticity was found, therefore once again no filtering was applied. The following table presents p -values obtained while testing for nonlinear Granger causality between ELC_{IND} , GDP and $EMPL$ (bold face was used to mark finding causality at a 10% level, p -values referring to the reduced sample are presented in square brackets):

INSERT TABLE 9 AROUND HERE

This time causality from ELC_{IND} to employment was found to be significant at a 10% level in both periods. However, this is not contrary to the conclusion formulated after an analysis of the results of the linear TY procedure (table 8) because evidence of causality in the pre-crisis subsample was clearly weaker than in a full sample (e.g. it was not statistically significant at 5% level). In general, the results of this part of our research provided solid evidence in favour of Conjecture 3. On the other hand, Conjecture 4 should rather be rejected.

6.3. Some econometric problems

The main problem related to the examination of causal links between the variables of interest is the lack of extensive datasets, which is typical in the case of countries in transition. This simply leads to low power of causality tests and forces the researcher to interpret the empirical results with a dose of caution as spurious results are likely to occur.

The problem of relatively poor power properties is especially visible in case of nonparametric tests. For example in table 7 significant causality (at the 10% level) was found only in 6 out of 72 cases. However, under the null hypothesis of no Granger causality, one would expect to find p -values smaller than or equal to 0.10 in at least 10% of all cases (i.e. around 7 significant relations could have come about by pure chance, even in the absence of any Granger causality). This remark provides a basis to state that in general the evidence supporting nonlinear causalities between ELC_{TOT} , GDP and $EMPL$ is rather weak.

If one analyses each direction of nonlinear causality separately (note that the risk of reporting spurious causality may be different for each of the six directions examined) the results presented in table 7 provide slightly more convincing evidence for the existence of significant relationships. The existence of statistically significant nonlinear causal relationships (some evidence of causality was reported for five out of the six directions examined) is still somewhat uncertain, since p -values smaller than 0.10 were found only in one or two out of the 12 cases examined for each significant link.⁹ Similar problems were encountered during the interpretation of the results of the nonparametric tests presented in table 9.

However, it should be underlined that the uncertainty regarding the results of the nonlinear tests does not change the major findings of the paper (i.e. the feedback between total electricity consumption and GDP as well as between total electricity consumption and employment, and the unidirectional causality running from industrial electricity consumption to employment), which were mainly based on the results of linear methods (including bootstrap variants).

Another issue related to the small sample size is the conclusion that in general the crisis period does not seem to affect the causal relations (linear and nonlinear). Since the pre-crisis subsample dominates the full sample (note the small sample size and the small difference between the pre-crisis subsample and the full sample), it is hard to expect that results

⁹ Even in the absence of causality, one significant (at the 10% level) relation (out of 12 cases) could easily have come about by pure chance, since $1/12 \approx 0.083 < 0.10$. However, obtaining two significant (at the 10% level) results for independent processes is less probable, since $2/12 \approx 0.167$. Therefore, in some cases results of nonlinear tests are significantly different from those which could be easily obtained by chance alone.

obtained for both periods would differ substantially. Moreover, Poland was the only European country with a positive rate of GDP growth in 2008 and 2009. The world financial crisis did not affect Poland as heavily as other countries, which was probably the second reason for the small difference in the results between the full sample and the pre-crisis subsample. In this context, finding a significant difference between the structures of causal dependences in both examined periods should be extensively discussed and analysed.

7. Concluding remarks

The main goal of this paper was the examination of causal interdependences between electricity consumption and GDP in Poland. We performed our research on total electricity consumption as well as on industrial electricity consumption. Our research was performed in a three-dimensional framework with employment chosen as an additional variable, since a simple two-dimensional approach involving only GDP and electricity consumption may be seriously biased due to the omission of important variables. We applied reliable quarterly data covering the period Q1 2000 – Q4 2009. However, we additionally examined the case of a reduced sample to investigate the possible impact of the world economic crisis on the structure of dynamic links between the variables. In order to test for causality we applied both traditional methods as well as some recently developed econometric tools.

We found relatively strong support for claiming that there was feedback between total electricity consumption and GDP as well as between total electricity consumption and employment in both periods. This may be interpreted as evidence of the fact that this structure of causal dependences between variables was relatively strong as it was not seriously disrupted during the crisis of 2008. It is also worth noting that this result was, in general, confirmed by two completely different econometric methods, which is especially important in terms of the validation and robustness of the empirical findings.

In contrast to total electricity consumption, we did not find such strong causal connections with other variables for industrial electricity usage in both periods, which was partly the consequence of the fact that in this case cointegration analysis could not be carried out in a three-dimensional framework. However, the data and computations showed evidence for claiming that the economic crisis of 2008 significantly supported the causal impact of industrial electricity consumption on employment.

To summarize, the results of our research provided a solid basis for accepting the feedback hypothesis for total electricity consumption and GDP as well as for total electricity consumption and employment in Poland. This result was robust in the face of the impact of the economic crisis and the type of econometric method used and proves that total electricity

consumption is an important factor determining fluctuations in economic growth and employment in Poland. On the other hand, industrial electricity consumption was found to have a direct causal impact on employment but not on GDP. We found especially strong evidence of the existence of this link when the crisis period was also taken into consideration.

In general, one may claim that results of this paper lead to the conclusion that in the recent decade the economic growth of Poland was dynamically linked by changes of electricity usage mostly in the non-industrial sector (residential usage, usage for commercial and public services etc.). This observation should be analyzed together with two facts. First, in the recent decade Polish industry has adopted new, more energy-efficient technologies in order to face a number of international ecological requirements. This could explain why growth in electricity consumption in this sector was not reported although there was a significant growth in the value of sold industrial production. Secondly, in recent years the share of the service sector in Polish GDP and employment has risen considerably. Thus, it is not surprising that increasing electricity consumption in this sector was significantly related to the economic growth of Poland.

One must not forget that the relatively small dataset available caused some statistical difficulties in this empirical study. The repetition of all calculations on the basis of longer time series therefore is likely to be an interesting research avenue for the future.

Taking into account the results presented in this paper - especially the detection of causality running from industrial electricity consumption to economic growth - Polish objections against a quick shift to clean energy is understandable. In the light of the empirical results the supposition that a quick shift of the Polish economy towards electricity production based on clean energy sources may significantly slow down the economic growth of the country is fully justified. Moreover, one may claim that the further reduction of greenhouse gas emissions in Poland and other new EU members will require significant financial and technological aid from highly developed EU members.

References:

- [1] Acaravci, A., Ozturk, I., 2010. Electricity consumption–growth nexus: Evidence from panel data for transition countries. *Energy Economics* 32, 604–608.
- [2] Agiakoglu, C., Newbold, P., 1992. Empirical Evidence on Dickey–Fuller Type Tests. *Journal of Time Series Analysis* 13, 471–483.
- [3] Altinay, G., Karagol, E., 2005. Electricity consumption and economic growth: evidence from Turkey. *Energy Economics* 27, 849–856.
- [4] Andrews, D.W.K., Buchinsky, M., 2000. A Three–Step Method for Choosing the Number of Bootstrap Repetitions. *Econometrica* 68, 23–52.
- [5] Baek E., Brock, W., 1992. A general test for Granger causality: Bivariate model. Technical Report, Iowa State University and University of Wisconsin, Madison.
- [6] Brock, W., 1991. Causality, chaos, explanation and prediction in economics and finance, in: Casti, J., Karlqvist, A. (Eds.), *Beyond Belief: Randomness, Prediction and Explanation in Science*. CRC Press, Boca Raton, Fla., pp. 230–279.
- [7] Chang, T., Fang, W., Wen, L.F., 2001. Energy consumption, employment, output, and temporal causality: evidence from Taiwan based on cointegration and error–correction modelling techniques. *Applied Economics* 33, 1045–1056.
- [8] Chen, S.–T., Kuo, H.–I., Chen, C.–C., 2007. The relationship between GDP and electricity consumption in 10 Asian Countries. *Energy Policy* 35, 2611–2621.
- [9] Diks, C.G.H., DeGoede, J., 2001. A general nonparametric bootstrap test for Granger causality, in: Broer, H.W., Krauskopf, W., Vegter, G. (Eds.), *Global analysis of dynamical systems*. Institute of Physics Publishing, Bristol, United Kingdom, pp. 391–403.
- [10] Diks, C.G.H., Panchenko, V., 2005. A note on the Hiemstra–Jones test for Granger non–causality. *Studies in Nonlinear Dynamics and Econometrics* 9, No. 2, Article 4.
- [11] Diks, C.G.H., Panchenko, V., 2006. A new statistic and practical guidelines for nonparametric Granger causality testing. *Journal of Economic Dynamics and Control* 30, 1647–1669.
- [12] Ferguson, R., Wilkinson, W., Hill, R., 2000. Electricity use and economic development. *Energy Policy* 28, 923–934.
- [13] Ghosh, S., 2009. Electricity supply, employment and real GDP in India: evidence from cointegration and Granger–causality tests. *Energy Policy* 37, 2926–2929.
- [14] Granger, C.W.J., 1969. Investigating causal relations by econometric models and cross spectral methods. *Econometrica* 37, 424–438.
- [15] Granger, C.W.J., Newbold, P., 1974. Spurious regression in econometrics. *Journal of Econometrics* 2, 111–120.
- [16] Granger, C.W.J., 1988. Some recent developments in the concept of causality. *Journal of Econometrics* 39, 199–211.
- [17] Granger, C.W.J., Huang, B., Yang, C., 2000. A bivariate causality between stock prices and exchange rates: evidence from recent Asian Flu. *The Quarterly Review of Economics and Finance* 40, 337–354.
- [18] Gurgul, H., Lach, Ł., 2009. Linear versus nonlinear causality of DAX companies. *Operations Research and Decisions* 3, 27–46.
- [19] Gurgul, H., Lach, Ł., 2010. The causal link between Polish stock market and key macroeconomic aggregates. *Betriebswirtschaftliche Forschung und Praxis* 4, 367–383.
- [20] Hacker, R.S., Hatemi–J, A., 2006. Tests for causality between integrated variables using asymptotic and bootstrap distributions: theory and application. *Applied Economics* 38, 1489–1500.
- [21] Halicioglu, F., 2007. Residential electricity demand dynamics in Turkey. *Energy Economics* 29, 199–210.
- [22] Hiemstra, C., Jones, J.D., 1994. Testing for linear and nonlinear Granger causality in the stock price–volume relation. *Journal of Finance* 49, 1639–1664.
- [23] Horowitz, J.L., 1995. Bootstrap methods in econometrics: Theory and numerical performance, in: Kreps, D.M., Wallis, K.F. (Eds.), *Advances in Economics and Econometrics: Theory and Applications*. Cambridge University Press, Cambridge, pp. 188–232.
- [24] Johansen, S., 1995. *Likelihood–based Inference in Cointegrated Vector Autoregressive Models*. Oxford University Press, Oxford.
- [25] Jumbe, C.B.L., 2004. Cointegration and causality between electricity consumption and GDP: empirical evidence from Malawi. *Energy Economics* 26, 61–68.

- [26] Keho, Y., 2007. Causal relationship between energy consumption and GDP: An empirical analysis of five West African countries. *The Journal of Energy and Development* 33, 23–32.
- [27] Lach, Ł., 2010. Application of bootstrap methods in investigation of size of the Granger causality test for integrated VAR systems. *Managing Global Transitions* 8, 167–186.
- [28] Lee, C.C., Chang, C.P., 2008. Energy consumption and economic growth in Asian economies: a more comprehensive analysis using panel data. *Resource and Energy Economics* 30, 50–65.
- [29] Lütkepohl, H., 1993. *Introduction to Multiple Time Series Analysis*, second ed. Springer–Verlag, New York.
- [30] Morimoto, R., Hope, C., 2004. The impact of electricity supply on economic growth in Sri Lanka. *Energy Economics* 26, 77–85.
- [31] Mozumder, P., Marathe, A., 2007. Causality relationship between electricity consumption and GDP in Bangladesh. *Energy Policy* 35, 395–402.
- [32] Narayan, P.K., Narayan, S., Prasad, A., 2008. A structural VAR analysis of electricity consumption and real GDP: Evidence from the G7 countries. *Energy Policy* 36, 2765–2769.
- [33] Narayan, P.K., Prasad, A., 2008. Electricity consumption–real GDP causality nexus: evidence from a bootstrapped causality test for 30 OECD countries. *Energy Policy* 36, 910–918.
- [34] Narayan, P.K., Singh, B., 2007. The electricity consumption and GDP nexus for the Fiji Islands. *Energy Economics* 29, 1141–1150.
- [35] Narayan, P.K., Smyth, R., 2005. Electricity consumption, employment and real income in Australia: evidence from multivariate Granger causality tests. *Energy Policy* 33, 1109–1116.
- [36] Narayan, P.K., Smyth, R., 2008. Energy consumption and real GDP in G7 countries: new evidence from panel cointegration with structural breaks. *Energy Economics* 30, 2331–2341.
- [37] Newey, W.K. West, K.D., 1987. A Simple Positive Semidefinite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix. *Econometrica* 55, 703–708.
- [38] Ozturk, I., 2010. A literature survey on energy–growth nexus. *Energy Policy* 38, 340–349.
- [39] Ozturk, I., Acaravci, A., 2011. Electricity consumption–real GDP causality nexus: Evidence from ARDL Bounds testing approach for 11 MENA countries. *Applied Energy* 88(8), 2885–2892.
- [40] Paulsen, J., 1984. Order determination of multivariate autoregressive time series with unit roots. *Journal of Time Series Analysis* 5, 115–127.
- [41] Payne, J.E. 2010. A survey of the electricity consumption–growth literature. *Applied Energy* 87, 723–731.
- [42] Pedroni, P., 1999. Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and Statistics* 61, 653–678.
- [43] Pedroni, P., 2004. Panel cointegration: asymptotic and finite sample properties of fooled time series tests with an application to the PPP hypothesis. *Econometric Theory* 20, 597–625.
- [44] Phillips, P.C.B., 1986. Understanding the spurious regression in econometrics. *Journal of Econometrics* 33, 311–340.
- [45] Shiu, A., Lam, P.L., 2004. Electricity consumption and economic growth in China. *Energy Policy* 32, 47–54.
- [46] Squalli, J., 2007. Electricity consumption and economic growth: bounds and causality analyses for OPEC members. *Energy Economics* 29, 1192–1205.
- [47] Toda, H.Y., Yamamoto, T., 1995. Statistical inference in vector autoregressions with possibly integrated processes. *Journal of Econometrics* 66, 225–250.
- [48] Wolde–Rufael, Y., 2006. Electricity consumption and economic growth: a time series experience for 17 African countries. *Energy Policy* 34, 1106–1114.
- [49] Yang, H.Y., 2000. A note of the causal relationship between energy and GDP in Taiwan. *Energy Economics* 22, 309–317.
- [50] Yoo, S.–H., 2005. Electricity consumption and economic growth: evidence from Korea. *Energy Policy* 33, 1627–1632.
- [51] Yoo, S.–H., 2006. The causal relationship between electricity consumption and economic growth in ASEAN countries. *Energy Policy* 34, 3573–3582.
- [52] Yoo, S.–H., Kwak, S.–Y., 2010. Electricity consumption and economic growth in seven South American countries. *Energy Policy* 38, 181–188.
- [53] Yoo, S.–H., Lee, J., 2010. Electricity consumption and economic growth: A cross–country analysis. *Energy Policy* 38, 622–625.
- [54] Yuan, J., Zhao, C., Yu, S., Hu, Z., 2007. Electricity consumption and economic growth in China: cointegration and co–feature analysis. *Energy Economics* 29, 1179–1191.

List of tables:

Description of variable	Unit	Abbreviation for seasonally adjusted and logarithmically transformed variable
Real quarterly gross domestic product in Poland	mln PLN	<i>GDP</i>
Employment in Poland based on quarterly Labour Force Survey	thousands	<i>EMPL</i>
Quarterly total electricity consumption in Poland	GWh	<i>ELC_{TOT}</i>
Quarterly industrial electricity consumption in Poland	GWh	<i>ELC_{IND}</i>

Table 1. Units, abbreviations and short description of examined variables.

Variable Quantity	<i>GDP</i>	<i>EMPL</i>	<i>ELC_{TOT}</i>	<i>ELC_{IND}</i>
Minimum	12.11 [12.11]	9.51 [9.51]	10.41 [10.41]	9.50 [9.73]
1 st quartile	12.15 [12.14]	9.53 [9.53]	10.46 [10.46]	9.82 [9.84]
Median	12.26 [12.24]	9.57 [9.56]	10.50 [10.49]	9.88 [9.88]
3 rd quartile	12.41 [12.35]	9.63 [9.59]	10.53 [10.53]	9.93 [9.95]
Maximum	12.49 [12.46]	9.68 [9.66]	10.57 [10.57]	10.09 [10.09]
Mean	12.28 [12.25]	9.58 [9.57]	10.50 [10.48]	9.87 [9.89]
Std. deviation	0.12 [0.11]	0.09 [0.04]	0.04 [0.04]	0.10 [0.07]
Skewness	0.27 [0.48]	0.48 [0.71]	0.01 [0.20]	-0.87 [0.44]
Excess kurtosis	-1.40 [-1.09]	-1.12 [-0.62]	-0.61 [-0.96]	1.93 [-0.01]

Table 2. Descriptive statistics of examined variables.

Test type	ADF				KPSS ^c		PP ^c	
	with constant		with constant and linear trend		with constant ^a	with constant and linear trend ^b	with constant	with constant and linear trend
	<i>p</i> -value	Optimal lag	<i>p</i> -value	Optimal lag	Test statistic		<i>p</i> -value	
<i>GDP</i>	0.99 [0.91]	1 [1]	0.19 [0.23]	1 [1]	1.08 [0.94]	0.23 [0.22]	0.98 [0.94]	0.52 [0.43]
<i>EMPL</i>	0.00 [0.13]	4 [4]	0.00 [0.35]	4 [4]	0.78 [0.53]	0.25 [0.24]	0.92 [0.97]	0.60 [0.95]
<i>ELC_{TOT}</i>	0.68 [0.81]	0 [0]	0.16 [0.15]	0 [0]	0.93 [0.63]	0.12 [0.13]	0.76 [0.89]	0.16 [0.12]
<i>ELC_{IND}</i>	0.24 [0.00]	1 [0]	0.35 [0.19]	4 [4]	0.33 [0.25]	0.23 [0.18]	0.03 [0.00]	0.09 [0.00]

Table 3. Results of stationarity analysis.

^a Critical values: 0.347 (10%), 0.463 (5%), 0.739 (1%).

^b Critical values: 0.119 (10%), 0.146 (5%), 0.216 (1%).

^c Bandwidth parameter was established according to Newey and West (1987).

Hypothesized number of cointegrating vectors	Eigenvalue	Johansen Trace test		Johansen Maximal Eigenvalue test	
		Trace statistic	<i>p</i> -value	Maximal Eigenvalue statistic	<i>p</i> -value
Zero	0.47 [0.58]	38.13 [39.54]	0.00 [0.00]	22.78 [26.24]	0.02 [0.00]
At most one	0.33 [0.35]	15.35 [13.29]	0.05 [0.10]	14.31 [12.95]	0.04 [0.07]
At most two	0.02 [0.01]	1.03 [0.33]	0.30 [0.56]	1.03 [0.33]	0.30 [0.56]

Table 4. Results of cointegration analysis for ELC_{TOT} , GDP and $EMPL$ variables.

Short-run								
Null hypothesis ^a	<i>p</i> -value ^c							
	Unrestricted				Sequential			
	Asymptotic		Bootstrap ^b		Asymptotic		Bootstrap ^b	
$ELC_{TOT} \nrightarrow GDP$	0.15 [0.14]		0.09 [0.10]		0.01 [0.00]		0.02 [0.03]	
$GDP \nrightarrow ELC_{TOT}$	0.12 [0.16]		0.16 [0.21]		0.01 [0.02]		0.04 [0.04]	
$ELC_{TOT} \nrightarrow EMPL$	0.55 [0.51]		0.43 [0.53]		NCL [NCL]		NCL [NCL]	
$EMPL \nrightarrow ELC_{TOT}$	0.00 [0.01]		0.00 [0.02]		0.00 [0.00]		0.01 [0.00]	
$GDP \nrightarrow EMPL$	0.69 [0.67]		0.61 [0.73]		0.08 [0.09]		0.02 [0.01]	
$EMPL \nrightarrow GDP$	0.10 [0.16]		0.07 [0.14]		0.00 [0.00]		0.00 [0.00]	
Long-run								
Equation	<i>p</i> -value of EC_1 component ^c				<i>p</i> -value of EC_2 component ^c			
	Unrestricted		Sequential		Unrestricted		Sequential	
	Asymptotic	Bootstrap ^b	Asymptotic	Bootstrap ^b	Asymptotic	Bootstrap ^b	Asymptotic	Bootstrap ^b
ELC_{TOT}	0.00 [0.00]	0.01 [0.00]	0.05 [0.00]	0.02 [0.00]	0.10 [0.15]	0.09 [0.17]	0.00 [0.07]	0.00 [0.01]
GDP	0.04 [0.02]	0.08 [0.01]	0.01 [0.03]	0.04 [0.04]	0.94 [0.95]	0.73 [0.68]	NCL [NCL]	NCL [NCL]
$EMPL$	0.18 [0.08]	0.25 [0.04]	0.02 [0.01]	0.05 [0.04]	0.01 [0.00]	0.00 [0.00]	0.00 [0.00]	0.00 [0.00]

Table 5. Analysis of causal links between ELC_{TOT} , GDP and $EMPL$ variables (VEC models).

^a The notation " $x \nrightarrow y$ " is equivalent to " x does not Granger cause y ".

^b Number of bootstrap replications established using Andrews and Buchinsky (2000) method varied between 1769 and 3119.

^c The symbol NCL is the abbreviation of "No coefficients left".

Null hypothesis ^a	p-value	
	Asymptotic	Bootstrap ^b
$ELC_{TOT} \neg \rightarrow GDP$	0.27 [0.43]	0.41 (N=2099) [0.52 (N=2279)]
$GDP \neg \rightarrow ELC_{TOT}$	0.05 [0.15]	0.07 (N=2659) [0.05 (N=3019)]
$ELC_{TOT} \neg \rightarrow EMPL$	0.71 [0.65]	0.58 (N=2219) [0.53 (N=2739)]
$EMPL \neg \rightarrow ELC_{TOT}$	0.03 [0.18]	0.02 (N=2019) [0.24 (N=2559)]
$GDP \neg \rightarrow EMPL$	0.72 [0.86]	0.64 (N=1679) [0.77 (N=1859)]
$EMPL \neg \rightarrow GDP$	0.53 [0.48]	0.42 (N=2219) [0.41 (N=2759)]

Table 6. Analysis of causal links between ELC_{TOT} , GDP and $EMPL$ variables (TY approach).

^a The notation " $x \neg \rightarrow y$ " is equivalent to " x does not Granger cause y ".

^b Parameter N denotes the number of bootstrap replications established according to Andrews and Buchinsky (2000) procedure.

Null hypothesis ^a	p-value					
	$b_{DP}=0.5,$ $l_{DP}=1$	$b_{DP}=1,$ $l_{DP}=1$	$b_{DP}=1.5,$ $l_{DP}=1$	$b_{DP}=0.5,$ $l_{DP}=2$	$b_{DP}=1,$ $l_{DP}=2$	$b_{DP}=1.5,$ $l_{DP}=2$
$ELC_{TOT} \neg \rightarrow GDP$	0.67 [0.43]	0.61 [0.35]	0.08 [0.20]	0.72 [0.56]	0.26 [0.09]	0.42 [0.59]
$GDP \neg \rightarrow ELC_{TOT}$	0.51 [0.35]	0.32 [0.57]	0.76 [0.46]	0.41 [0.64]	0.61 [0.05]	0.81 [0.77]
$ELC_{TOT} \neg \rightarrow EMPL$	0.62 [0.57]	0.72 [0.58]	0.16 [0.23]	0.52 [0.59]	0.73 [0.66]	0.06 [0.29]
$EMPL \neg \rightarrow ELC_{TOT}$	0.55 [0.26]	0.81 [0.92]	0.34 [0.37]	0.29 [0.44]	0.76 [0.49]	0.17 [0.09]
$GDP \neg \rightarrow EMPL$	0.49 [0.47]	0.09 [0.19]	0.81 [0.76]	0.43 [0.32]	0.30 [0.28]	0.70 [0.83]
$EMPL \neg \rightarrow GDP$	0.68 [0.58]	0.17 [0.36]	0.45 [0.42]	0.38 [0.26]	0.56 [0.82]	0.31 [0.27]

Table 7. Analysis of nonlinear causal links between ELC_{TOT} , GDP and $EMPL$ variables (post-TY residuals).

^a The notation " $x \neg \rightarrow y$ " is equivalent to " x does not Granger cause y ".

Null hypothesis ^a	<i>p</i> -value ^b	
	Asymptotic	Bootstrap ^b
$ELC_{IND} \neg \rightarrow GDP$	0.22 [0.72]	0.24(N=1879) [0.53 (N=2099)]
$GDP \neg \rightarrow ELC_{IND}$	0.61 [0.86]	0.66 (N=2579) [0.72 (N=2819)]
$ELC_{IND} \neg \rightarrow EMPL$	0.06 [0.28]	0.04 (N=2019) [0.35 (N=2359)]
$EMPL \neg \rightarrow ELC_{IND}$	0.48 [0.65]	0.57 (N=1919) [0.72 (N=2139)]
$GDP \neg \rightarrow EMPL$	0.54 [0.82]	0.39 (N=1999) [0.57 (N=2279)]
$EMPL \neg \rightarrow GDP$	0.67 [0.88]	0.79 (N=2239) [0.72 (N=2439)]

Table 8. Analysis of causal links between ELC_{IND} , GDP and $EMPL$ variables (TY approach).

^a The notation " $x \neg \rightarrow y$ " is equivalent to " x does not Granger cause y ".

^b Parameter N denotes the number of bootstrap replications established according to Andrews and Buchinsky (2000) procedure.

Null hypothesis ^a	<i>p</i> -value					
	$b_{DP}=0.5,$ $l_{DP}=1$	$b_{DP}=1,$ $l_{DP}=1$	$b_{DP}=1.5,$ $l_{DP}=1$	$b_{DP}=0.5,$ $l_{DP}=2$	$b_{DP}=1,$ $l_{DP}=2$	$b_{DP}=1.5,$ $l_{DP}=2$
$ELC_{IND} \neg \rightarrow GDP$	0.76 [0.49]	0.84 [0.54]	0.83 [0.45]	0.25 [0.32]	0.81 [0.52]	0.76 [0.64]
$GDP \neg \rightarrow ELC_{IND}$	0.19 [0.42]	0.82 [0.67]	0.13 [0.24]	0.73 [0.67]	0.69 [0.71]	0.43 [0.55]
$ELC_{IND} \neg \rightarrow EMPL$	0.23 [0.35]	0.47 [0.79]	0.19 [0.34]	0.69 [0.43]	0.18 [0.40]	0.04 [0.09]
$EMPL \neg \rightarrow ELC_{IND}$	0.34 [0.19]	0.63 [0.81]	0.45 [0.58]	0.70 [0.62]	0.92 [0.67]	0.52 [0.37]
$GDP \neg \rightarrow EMPL$	0.65 [0.77]	0.46 [0.34]	0.65 [0.38]	0.45 [0.82]	0.78 [0.83]	0.65 [0.72]
$EMPL \neg \rightarrow GDP$	0.82 [0.39]	0.78 [0.65]	0.82 [0.72]	0.67 [0.34]	0.82 [0.49]	0.52 [0.63]

Table 9. Analysis of nonlinear causal links between ELC_{IND} , GDP and $EMPL$ variables (post-TY residuals).

^a The notation " $x \neg \rightarrow y$ " is equivalent to " x does not Granger cause y ".

List of figures:

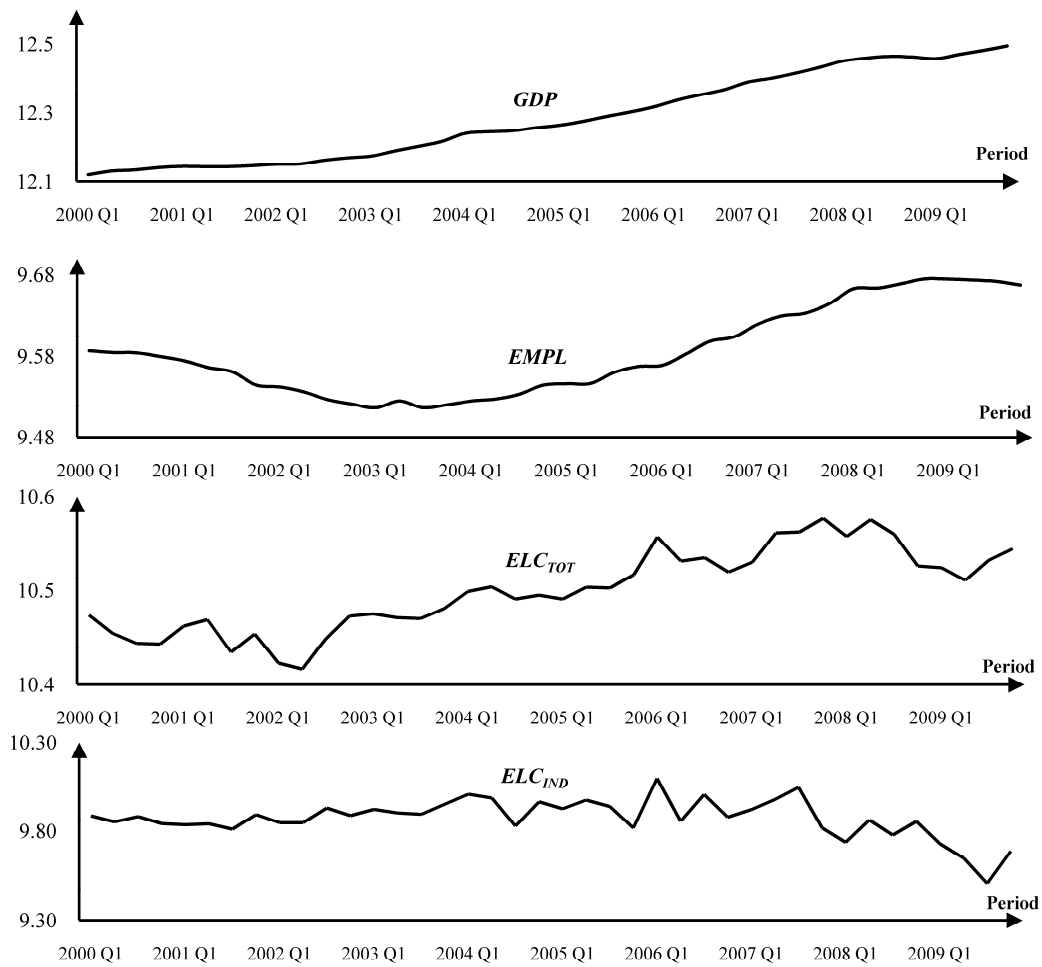


Figure 1. Plots of examined time series.