International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2015, 5(3), 869-888.

Energy-Gross Domestic Product Nexus: Disaggregated Analysis for the Czech Republic in the Post-Transformation Era

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ABSTRACT

This article contribution is two-fold. It presents new results based on quarterly frequency disaggregated data for the Czech Republic. It also goes through extensive identification of methodological deficiencies present in the literature and proposes a methodology to determine the direction and also the sign of the causality in the energy-economy nexus. The proposed improvements are illustrated on the case of Czech Republic during the period 1996-2011 in quarterly frequency. The data are taken in disaggregated form; the model estimates cover aggregate and sectoral levels of final energy consumption, and also fuel-specific consumption and sectoral electricity consumption. The evidence for the conservation hypothesis with a positive sign of the causality is found for, (i) The consumption of the solid fuels, (ii) the electricity consumption in the transportation sector, (iii) the final energy consumption of the industrial sector, and (iv) the electricity consumption of the industrial sector. Given the fact the solid fuels are: (a) Used heavily for the electricity generation in the Czech Republic, (b) the main differentiating fuel between the Czech and European Union industrial energy consumption, and (c) could contribute to the other environmental targets, it seems reasonable to favor the reduction of the solid fuels consumption in the Czech energy conservation plans.

Keywords: Energy, Gross Domestic Product, Energy conservation, Czech Republic
JEL Classification: Q43

1. INTRODUCTION

This paper examines the causal links between the energy consumption and the economic growth. The structure of the paper is as follows. First the energy-economy nexus is explained in detail, including motivation, classification and common deficiencies. Subsequent literature review provides detailed overview of the samples, variables and methods used in the recent papers. The literature review then serves as a basis for the identification of common methodological deficiencies, including the proposal on how to tackle them.

As the empirical part of the article applies the new proposal to Czech Republic (which has been so far almost ignored in the literature), the detailed description of the Czech energy sector is included as well. Following is the description of the methodology and data used in the estimation.

Results are presented in detail with the following classification: Aggregate consumption models, sectoral models using final energy consumption, sectoral models using electricity consumption and models using specific consumption of various types of fuels. Model designations are provided in Table 1.

1.1. Link between Energy Conservation and CO_2 Emissions

The motivation for the energy conservation investigation in general stems from the effort to reduce the greenhouse gas (GHG) emissions, and consequent energy conservation policies. In European Union (EU) member countries, obligatory measures implementing the energy conservations were primarily initiated by the Energy Policy for Europe (continually extended).[1]

1 This first European supranational energy policy (also known as the 20-20-20 strategy) was introduced in response to the Kyoto protocol commitment of the European Union to reduce the emissions of the greenhouse gases (GHG). This policy is represented by the three goals that should be reached by the year 2020: 20% reductions in the carbon dioxide emissions, 20% share of renewables in the energy mix and 20% reduction of the primary energy consumption by the year 2020. Recently, the EU's Roadmap to 2050 Strategy has further extended the goals (40% GHG reduction by 2030 and 80% by 2050).

The link between the commitment to reduce the GHG emissions and energy conservation can be best illustrated with the so-called Kaya identity.

The Kaya identity can be expressed as $C = N \cdot \frac{GDP}{N} \cdot \frac{E}{GDP} \cdot \frac{C}{E}$, where C stands for the carbon emissions, N for population, $\frac{GDP}{N}$ the economic level (gross domestic product [GDP] per capita), $\frac{E}{GDP}$ the primary energy intensity, and $\frac{C}{E}$ the carbon intensity of energy (Hoffert and Caldeira, 2004).

The first two factors in the identity are of little use for a policy maker. Lowering these factors would imply a regulation of the population growth or the economic recession. The third factor, the carbon intensity, is probably the most difficult to change due to fuel source constraints.

What is remaining is the energy intensity, one of the leading target indicators in the energy policies. As with the carbon intensity, the change in the energy efficiency is costly, often limited by technological and profitability constraints (and the effects of the efficiency improvements can be diminished by the so-called feedback effect).

Effectively this means the GHG commitments tend to be answered by the reduction in E in the energy policies. de Nooij et al. (2003) document the majority of the industrialized countries indeed focus on the reduction of the total domestic energy use in their energy and environmental policies. MPO (2012) provides the overview of the measures and regulations that are in place to influence the structure of energy consumption in the Czech Republic in relation to the implementation of the European Directive 2009/28/EC.

Table 1: Overview of the model designations

Energy variables	Bivariate	Multivariate W/O price measure	Multivariate W/price measure
Final energy consumption models			
Total	B1	F1	F2
Agriculture	C1	J1	K1
Industry	C2	J2	K2
Other	C3	J3	K3
Residential	C4	J4	K4
Services	C5	J5	K5
Transport	C6	J6	K6
Electricity consumption models			
Total consumption	B2	G1	G2
Industry	D1	L1	M1
Transport	D2	L2	M2
Construction	D3	L3	M3
Agriculture	D4	L4	M4
Residential	D5	L5	M5
Services	D6	L6	M6
Other	D7	L7	M7
Fuel specific consumption models			
Total	B3	H1	H2
Solid	E1	N1	O1
Nuclear	E2	N2	O2
Natural gas	E3	N3	O3
Petrol	E4	N4	O4
RES	E5	N5	O5

RES: Renewable energies

This article starts with the explanation of the relationship between the energy consumption and the economic growth, including the theoretical background and overview of the energy-economy nexus literature. The consequent text provides detailed discussion of the problems associated with the topic and explains the significance of the determination of the causality sign. The proposed methodology is applied using the quarterly frequency data for the Czech Republic during the period 1996-2011.

This "limitation" is intentional. Most of the studies of this type focus on a panel of countries. Typically, the model specification is preselected and the results are compared across the countries. This study instead selects a solitary cross section and investigates the results across the various specifications.

Another reason for the country selection is simply tied to the fact the energy-economy nexus was not yet investigated in detail in the Czech Republic, despite the obligation to implement the energy conservation plans resulting from the EU-level energy policy.

The main purpose of the focus on the specifications (rather than taking specification as granted) is the ongoing disputation in the literature about what energy factors are important in the energy-economy nexus. As the implementation of the EU 20-20-20 policy is carried out on the national level by the means chosen by the individual country, the policy implications are usually limited to the national level as well, which further speaks for the use of a single country in the empirical papers (even though statistically speaking the panels are more efficient).

The reliable data covering the post-communist countries are inherently limited to the period after the collapse of the Eastern Bloc. This limits the ability to estimate multivariate vector autoregressive (VAR) models in single country studies using the annual data. Unlike the vast majority of the studies this text utilizes quarterly frequency of the data.

2. THE ENERGY-ECONOMY NEXUS OVERVIEW

The energy-economy nexus deals with the identification of the causality between the energy consumption and the economic growth.

Unlike the situation in the 1970s and 1980s, the main cause of the energy consumption reduction nowadays is the international struggle to reduce the emissions of the GHGs (as illustrated by the Kaya identity).

Researches have given quite a lot of attention to the energy-economy nexus investigation. This is evidenced in literature surveys, see e.g. Mahadevan and Asafu-Adjaye (2007); Sari and Soytas (2007); Ozturk (2010); Ozturk and Acaravci (2010); Payne (2010b); Payne (2010a); Ozturk and Uddin (2012); Menegaki (2014); Kalimeris et al. (2014) or Isa et al. (2015).

Despite the fact there seems to be strong empirical evidence against the neutrality hypothesis in general, the dichotomy of the results gives grounds for the criticism of this largely exploratory topic. So far there is no indication of consensus in the literature.

Comparison of the results in the literature clearly shows the results are contradictory even with small changes in the underlying country and time sampling. This issue comes forward especially in cases of panel data estimates. While panel data models often offer more observations, and hence seemingly better statistical properties, it is necessary to consider their limitations in the context of energy-economy nexus. Despite being rarely acknowledged, one of the basic assumptions related to panel data models is the homogeneity of the groups. If this condition is not met, the results cannot be generalized and remain of little use for the individual countries.

Essentially, there are two-ways to tackle this problem. One is to use groups which are sufficiently homogenous. This recommendation can be found e.g. in Payne (2010b), who argues to only employ groups of countries with similar energy consumption patterns and development status (typically only possible for relatively small panels). The other is to use panel models with random coefficients. To the author's knowledge, none of the articles regarding energy-economy nexus in the panel framework has chosen this approach (though it is in essence very similar to obtaining the estimation results for individual countries).

Given the standpoint of the practical application it is favorable to employ the coherent groups that can provide applicable policy recommendations in all countries involved. This article accepts this view and takes the natural starting point of a single country carefully examined in the variety of model specifications.

As argued in Karanfil (2009) the research papers focusing only on different samples have no further research potential. If there is uncertainty regarding what energy variables should be employed, this logically leads to results that hardly comparable. Kalimeris et al. (2014) also point out that "an effort to evaluate and incorporate energy price fluctuations and price elasticities is absent from the vast majority of studies published within the causality debate." As will be shown in the empirical part of this paper, the inclusion of the price variable is indeed an important factor in the determination of the causality in the Czech Republic.

2.1. Basic Hypotheses

There are four main hypotheses related to the energy-economy nexus. The neutrality hypothesis, the feedback hypothesis, the growth hypothesis and the conservation hypothesis. The direction of causality described by these hypotheses is shown in Table 2. While this classification is widely accepted, it only considers the direction of the causality. The hypotheses that can be found in the literature tacitly assume that the sign of the causality is positive. Only handful of studies even takes a look at the signs of the coefficients and even then it is typically limited to the coefficients in the co-integration equation(s). Obviously, the reversal of the sign of the causality also reverses the typical policy implications associated with the given hypothesis. This stresses the need to identify not only the direction of the causality, but also whether the causal relationship is positive or negative.

The motivation for the energy-GDP nexus investigation today is almost solely energy conservation policies. The actual implementation of energy conservation policies is quite resourceful with its multitude of regulations. In general, there are both direct and indirect measures, but it is not uncommon to find a presence of the direct consumption reduction acts. However, it seems the actual policy is more or less uninterested in the whole research agenda – evidenced by the absence of any remarks to this research area on EU's portal europa.eu (interested reader is invited to run the full-text search [e.g., Google] of either expected keywords such as "energy-GDP nexus," titles of even the most cited papers, or the names of the authors of the research papers on both europa.eu portal or Czech Ministry of Industry and Trade portal mpo.cz, yielding zero results).

The neutrality hypothesis expects no causality between the economic growth and the energy consumption. This implies neither the energy conservation or expansion policies will affect the economic growth and vice versa. Naturally it serves as the null hypothesis in both co-integration and causality tests. One of the basic arguments for the validity of the neutrality hypothesis is that the energy expenditures represent only a small fraction of the GDP. Therefore it is not likely that even the significant changes in the energy consumption will have very distinct effects on the GDP, or that these effects will be effectively overshadowed by other factors. A somewhat different scope of arguments is focusing on the structure of the economy. It is expected that with time (and higher levels of development), the production structure will be shifting towards the service sector (that is typically less energy intensive). Such a structural change, typically evidenced by the significant energy intensity changes, may lead to what is often labeled as decoupling of the energy use and GDP. This decoupling would explain the absence of evidence for the causality (especially if considered only on the aggregate levels).

The support of this hypothesis can also be provided by the absence of the actual physical link between the variables in the typical yearly frequency estimations. There is only limited possibility to store the energy consumed in previous periods (and hardly for lengths of years). Then the volumes of the past energy consumption cannot have a reasonable physical linkage to the current output. While this argument is not reasonably applicable to all types of the hypotheses, the statistical evidence of growth hypothesis against the neutrality might be easily disputed with the absence of actual growth-inducing

Table 2: The basic types of energy-economy relationships

Designation	Description
The neutrality hypothesis	No causality between *E* and *GDP*
The conservation hypothesis	Uni-directional causality: $E \leftarrow GDP$
The growth hypothesis	Uni-directional causality: $E \rightarrow GDP$
The feedback hypothesis	Bi-directional causality: $E \leftrightarrow GDP$

GDP: Gross domestic product

process. From the energy conservation policy viewpoint, the neutrality hypothesis is a favorable outcome as there is no second round penalty from the energy conservation. Bi-directional feedback hypothesis represents the opposite point of view, with the mutual interdependence of the energy consumption and economic growth, their joint determination and bi-directional causality. The policies implications need to take into the account the expected behavior of the economy given the specific form the relationship both for the design and for the effects of the proposed energy policy.

Unlike other types of hypotheses, this usually requires additional policy investigation (ideally based on more detailed information datasets), or the policy design that needs to specify the hierarchy of the targets. From the energy conservation policy viewpoint, the feedback hypothesis is not a favorable outcome as there might be a second round penalty from the energy conservation. The remaining two uni-directional hypotheses are probably the most interesting ones (for the energy conservation policies). These may be found either from the economic growth to the energy consumption (the conservation hypothesis) or from the energy consumption to the economic growth (the growth hypothesis). The conservation hypothesis is usually favored by economists, who consider the energy primarily as the intermediate product. Therefore, with the increasing level of output there will be an increasing demand for goods and services, including the derived demand for energy. The evidence for the conservation hypothesis lends support for the energy conservation policy implementation. The growth hypothesis considers the energy as a necessary production factor. It is typically favored by the engineers and the applied physicists (Beaudreau, 2010) and implies the reductions in the energy supply (or consumption) will negatively influence the economic growth. The usual implication of the growth hypothesis is that the energy conservation should not be implemented in order to prevent potential constriction of the economic growth.

All these hypotheses tacitly assume the sign of the causality is positive. Among the scarce exceptions recognizing the sign of the causality are Gross (2012); Narayan and Popp (2012); Bowden and Payne (2009) and Sari and Soytas (2007). The possible negative sign of the causality might render the typical policy recommendation moot as the implications of the negative sign of causality are reversed between the growth and conservation hypotheses. While the literature so far ignored the impacts of the sign of the causality, there are no established names for the alternative types of hypothesis. In the results section the standard classification is used, but the sign of the causality is reported in each case.

2.2. Literature Review

The detailed results of the literature review are summarized in Table 3 (describing area, time frame and scope) and Table 4 (describing the variables and methods used).

Table 3: Overview of the selected articles regarding the energy-economy

Author (s)	Area	Estimated relationship	Time frame	Scope	Energy type
Gross (2012)	USA	Feedback in the transport sector Conservation in the commercial sector	1970-2007	Macro and sectoral level	Thermal aggregate
Narayan and Popp (2012) and Narayan et al. (2010)	93 countries	Conservation in 45 countries Growth in 18 countries	1980-2006	Macro level	Thermal aggregate
Nazlioglu et al. (2011)	14 countries	Neutrality in 11 countries Conservation in UK and Spain Growth in Hungary	1980-2007	Macro level	Nuclear
Menegaki (2011)	EU-27 countries (including)	Neutrality	1997-2007	Macro level	Renewables
Warr and Ayres (2010)	USA	Conservation	1946-2000	Macro level	Exergy and "Useful work"
Apergis et al. (2010)	19 countries	Growth in the short run Feedback in the long run	1984-2007	Macro level	Nuclear, renewables
Apergis and Payne (2010)	16 countries	Feedback in the short run Growth in the long run	1980-2005	Macro level	Nuclear
Acaravci and Ozturk (2010)	15 countries (including)	Neutrality	1990-2006	Macro level	Electricity
Bowden and Payne (2009)	USA	Neutrality in the transport sector Growth in the industrial sector Feedback in the commercial and residential sectors	1949-2006	Macro and sectoral level	Thermal aggregate
Yoo and Ku (2009)	6 countries	Neutrality in Argentina and Germany Conservation in France and Pakistan Growth in Korea Feedback in Switzerland	1965-2005	Macro level	Nuclear
Narayan and Prasad (2008)	30 countries (including)	Neutrality in 19 countries Conservation in Finland, Hungary and the Netherlands Growth in Australia, Italy, the Slovak Republic, the Czech Republic and Portugal Feedback in Iceland, Korea and the UK	1960-2002	Macro level	Electricity

Contd...

Table 3: ***(Continued)***

Author (s)	Area	Estimated relationship	Time frame	Scope	Energy type
Chontanawat et al. (2008)	108 countries (including)	Growth in 21 OECD (including) and 36 non-OECD countries Feedback in Finland, the Netherlands, Norway, Switzerland and 7 non-OECD countries	1960-2000	Macro level	Thermal aggregate
Narayan and Smyth (2008)	G-7 countries	Growth	1972-2002	Macro level	Thermal aggregate
Sari and Soytas (2007)	Six developing countries	Growth	1971-2002	Macro level	Thermal aggregate
Mahadevan and Asafu-Adjaye (2007)	20 countries	Growth in energy-importing countries Feedback in energy-exporting countries	1971-2002	Macro level	Thermal aggregate
Zachariadis (2007)	G-7 countries	Neutrality in USA mixed (method-dependent) in other countries	1949-2004 for USA 1960-2004 for other countries	Macro and sectoral level	Thermal aggregate
Lee (2006)	G-11 countries	Neutrality in the United Kingdom, Germany and Sweden Conservation in France, Italy and Japan Growth in Canada, Belgium, the Netherlands and Switzerland Feedback in USA	1960-2001	Macro level	Thermal aggregate
Sari and Soytas (2006)	G-7 countries	Neutrality in France Conservation in Germany, Italy, Japan and UK Growth in USA Feedback in Canada	1960-2004	Macro level	Thermal aggregate
Yoo (2006)	4 ASEAN countries	Conservation in Indonesia and Thailand Feedback in Malaysia and Singapore	1971-2002	Macro level	Electricity
Lee (2005)	18 developing countries	Growth	1975-2001	Macro level	Thermal aggregate
Ghali and El-Sakka (2004)	Canada	Feedback	1961-1997	Macro level	Thermal aggregate
Sari and Soytas (2004)	Turkey	Growth	1969-1999	Macro level	Thermal aggregate and 7 disaggregated energy sources
Wolde-Rufael (2004)	Shanghai (China)	Growth	1952-1999	Industrial sector	Thermal aggregate and 4 disaggregated energy sources
Sari and Soytas (2003)	17 countries	Conservation in Italy and Korea growth in Turkey, France, Germany and Japan Feedback in Argentina	1950-1992	Macro level	Thermal aggregate
Hondroyiannis et al. (2002)	Greece	Growth	1960-1996	Macro and sectoral level	Thermal aggregate
Asafu-Adjaye (2000)	Four Asian economies	Growth in India and Indonesia feedback in Thailand and the Philippines		Macro level	Thermal aggregate
Stern (2000)	USA	Growth	1948-1994	Macro level	Thermal aggregate in quality-adjusted index of energy input
Yang (2000)	Taiwan	Feedback	1954-1997	Macro level	Thermal aggregate and 4 disaggregated energy sources
Masih and Masih (1996)	Six Asian economies	Conservation in Indonesia growth in India Feedback in Pakistan	1955-1991	Macro level	Thermal aggregate

Table 4: Data and methods in the reviewed articles

Author (s)	Method	Multivariate/Bivariate	Sign recognition
Gross (2012)	ARDL bounds testing (Pesaran et al., 2001)	Multivariate (Real fixed capital stock, sectoral value added, final energy consumption, energy price, international trade)	Y (coefficients/elasticities)
Narayan and Popp (2012) and Narayan et al. (2010)	Panel long-run Granger causality using the method by Canning and Pedroni (2008)	Bivariate (Real GDP, energy consumption)	Y (coefficients/elasticities)
Nazlioglu et al. (2011)	Panel Granger causality approach by Kónya (2006) and causality test by Toda and Yamamoto (1995)	Multivariate (Energy consumption, real GDP, real gross fixed capital formation, labor force)	N
Menegaki (2011)	Panel co-integration test and Granger causality test using Engle and Granger (1987) two-step procedure	Multivariate (Real GDP per capita, consumption share of RES, final energy consumption, greenhouse emissions, employment rate)	Y (coefficients/elasticities)
Warr and Ayres (2010)	VECM and Wald tests	Multivariate (GDP, capital, labor, exergy/"useful work")	N
Apergis et al. (2010)	Panel error correction framework by Larsson et al. (2001)	Multivariate (Real GDP, nuclear electricity net consumption, total renewable electricity net consumption, total carbon dioxide emissions)	Y (coefficients/elasticities)
Apergis and Payne (2010)	Heterogeneous panel co-integration test (Pedroni, 1999; 2004)	Multivariate (Real GDP, real gross fixed capital formation, total labor force, net nuclear electric power consumption)	Y (coefficients/elasticities)
Acaravci and Ozturk (2010)	Panel co-integration test (Pedroni, 1999; 2004) and Granger causality test using Engle and Granger (1987) two-step procedure	Bivariate (Real GDP, electricity consumption)	N
Bowden and Payne (2009)	Toda and Yamamoto (1995) causality test	Multivariate (Primary energy consumption (total and sectoral), GDP, gross fixed capital formation, total civilian employment)	Y (sum of lagged coefficients in the VAR in levels)
Yoo and Ku (2009)	VECM, Granger causality tests and Hsiao (1981) modification of the Granger causality tests	Bivariate (Nuclear energy consumption, real GDP)	N
Narayan and Prasad (2008)	Bootstrapped Granger causality tests	Bivariate (Real GDP and electricity consumption)	N
Chontanawat et al. (2008)	Hsiao (1981) modification of the Granger causality tests	Bivariate (Real GDP and energy consumption)	N
Narayan and Smyth (2008)	Pedroni (1999) panel co-integration with structural breaks	Multivariate (Real GDP per capita, energy consumption p.c., real gross fixed capital formation p.c.)	Y (coefficients/elasticities)
Sari and Soytas (2007)	Pedroni (1999) panel co-integration and Granger causality test using Engle and Granger (1987) two-step procedure	Multivariate (Real GDP per capita, energy consumption p.c., CPI)	Y (coefficients/elasticities)
Mahadevan and Asafu-Adjaye (2007)	Generalized impulse response technique	Multivariate (Real GDP, energy consumption, gross capital formation, total labor force)	Y (impulse response)
Zachariadis (2007)	VECM, Toda and Yamamoto (1995) causality test and ARDL bounds testing (Pesaran et al., 2001)	Bivariate (Real GDP, Final energy consumption [total and sectoral])	N
Lee (2006)	Causality test by Toda and Yamamoto (1995)	Bivariate (Real GDP per capita, total energy consumption)	N
Sari and Soytas (2006)	Granger causality tests in VECM	Multivariate (Real GDP per capita, total energy use, total labor force , real gross fixed capital formation)	N
Yoo (2006)	Granger causality test using Engle and Granger (1987) two-step procedure and Hsiao (1981) modification of the Granger causality tests	Bivariate (Real GDP, electricity consumption)	N
Lee (2005)	Pedroni (1999) panel co-integration and Pedroni (2000) FMOLS	Multivariate (Real GDP, energy consumption, real capital stock)	N
Ghali and El-Sakka (2004)	Granger causality tests in VECM	Multivariate (Real GDP, energy consumption, capital stock, total employment)	N
Sari and Soytas (2004)	Forecast error variance decomposition (Koop et al., 1996; Pesaran and Shin, 1998)	Multivariate (Real GDP, employment, disaggregate categories of the energy consumption (total, coal, oil, hydraulic power, asphaltite, lignite, waste, wood))	N

Contd...

Table 4: ***(Continued)***

Author (s)	Method	Multivariate/Bivariate	Sign recognition
Wolde-Rufael (2004)	Toda and Yamamoto (1995) method of causality testing	Bivariate (Real GDP, energy consumption [coal, coke, electricity, oil and total])	N
Sari and Soytas (2003)	VECM and variance decomposition	Bivariate (Real GDP per capita, total energy consumption)	N
Hondroyiannis et al. (2002)	VECM	Multivariate (Real GDP, energy consumption, CPI)	N
Asafu-Adjaye (2000)	Granger causality tests	Multivariate (Real GDP, energy consumption per capita, CPI)	N
Stern (2000)	VECM	Multivariate (Aggregate capital stock, Total hours worked, quality-adjusted Divisia index of the BTU)	N
Yang (2000)	Hsiao (1981) modification of the Granger causality tests	Bivariate (Real GDP, disaggregate categories of the energy consumption [total, coal, oil, natural gas, and electricity])	N
Masih and Masih (1996)	Granger causality tests in VECM	Bivariate (Real GNP, Total consumption)	N

Y indicates the study takes into the account a sign of the relationship (in any form). *N* indicates the sign of the relationship or causality has not been considered. VECM: Vector error correction model, GDP: Gross domestic product, CPI: Consumer price index, RES: Renewable energies

As is evident from the literature, only approximately 60% of the studies use multivariate approach - i.e. use additional control variables besides GDP and energy consumption. Vast majority of the multivariate studies however only employs more than one control variable (typically, capital or labor).

A measure of the energy prices was included in only four studies, (+ Stern [2000] who used quality adjusted measure of energy), but only two of these controlled for capital (labor was omitted in all four cases). Less than a third of the studies have focused on a single cross-section (typically one country). The mean number of cross-sections in the studies was six. Five of the studies have decided to employ a sectoral consumption, while the rest relied on the aggregate consumption values.

The choice of the energy variable is typically not given much attention. Thermal aggregate values have been employed in the vast majority of the studies. Four studies relied on the nuclear heat, 3 used electricity consumption, 1 on used renewables and 1 study has employed exergy instead of energy. The distinction of the fuel type (in aggregate and fuel-specific consumption) was used in only three studies (+ Apergis et al. [2010] employed only renewable energies (RES) and nuclear heat, but not an aggregate). The literature shows as the most prolific either the standard Granger causality tests in VAR or vector error correction model (VECM) (13 studies) or modified Granger causality tests studies (eight studies, but only two of these used multivariate settings). Five studies employed panel co-integration methods only, without causality testing. One study employed the autoregressive distributed lag co-integration approach, and one study employed generalized impulse response technique and forecast error variance decomposition. As for the sign of the causality, 60% of the studies ignore the issue altogether. Remaining studies typically rely on the sign of a single elasticity coefficient (a solitary exception is Sari and Soytas [2007], but their method lacks the causality testing).

The following list characterizes the stylized facts of the energy-GDP nexus methodology:

- The distinction of energy sources forms two separate branches: Either the thermal aggregate consumption or the fuel-specific consumption. Of the fuel-specific branch, the major attention is usually paid to: Nuclear energy, electricity and RES.
- Majority of the studies rely on the aggregate data in thermal equivalent.
- The use of disaggregated data may reveal relationships that remain undiscovered in the higher levels of aggregation (Gross [2012] argues this situation is an example of "Simpson's Paradox" [Simpson, 1951] and recommends the Granger causality between energy and growth should be analyzed on the sectoral level only)
- The typical effort is to use longest sample possible, but ignores structural changes over the period of several decades. These longer time frame samples show somewhat higher potency in the detection of energy-economy causality. This issue might be related to the gradually decreasing energy intensity (especially prominent in the USA after the oil crises) in the later years (this development is sometimes labeled as the "de-coupling" of energy use and economic activity). It is therefore questionable whether the causalities found in the studies spanning several decades are not primarily based on the oldest data in the sample, before the de-coupling has taken place, while the later periods with the influence of de-coupling, could be best described with the neutrality hypothesis
- While the bivariate models' strong advantage is they can be employed even in the countries with limited availability of the data, the possibility of omitted variable bias advocates a multivariate framework with the inclusion of measures of both capital and labor. There is an inclination for the energy and labor being substitutable, as the energy is typically used to perform work (or that labor is a certain type of energy as well). However, in a typical environment, the ability to perform the substitution of labor with energy, the changes in capital are typically necessary. The inclusion of these measures in the multivariate framework remains scarce.
- The modified Granger causality tests are rarely employed.
- The causality testing *per se* is insufficient and the sign of the impact has to be taken into consideration.

- The sign of the causality is usually determined in an insufficient manner.

2.3. Causality Tests

The common approach to study the causality between groups of variables is to use the vector autoregression to describe the dynamic interactions between the variables.

The details of co-integration modeling, VAR, VECM and causality testing are well known. Apart from these, there are also less widespread approaches to Granger causality testing. The notable approaches to more reliable causality testing are two the modifications proposed by Hsiao (1981) and, for cases of non-stationary variables, the method suggested by Toda and Yamamoto (1995). For panel frameworks, the typical approach is most often based on the panel Granger causality test - essentially just standard Granger causality testing on stacked data, in practice this is not very informative, as it leads to averaging of the tests for individual cross sections. The recent contribution by Hatemi (2011) provides an interesting perspective on the panel causality testing, but it is not yet very common in the energy-economy nexus literature. In this study, the variables were found to be non-stationary, hence Toda and Yamamoto (1995) method was preferred, with well documented advantages of higher power, less pre-testing bias, robustness to the presence of unit roots, allowance for different orders of integration of the variables being tested and better control of the Type I error probability with little to no loss in power. See for instance Clarke and Mirza (2006) for more detailed discussion based on simulation results and comparison with other methods.

Hsiao (1981) recommends determining the optimal lag length in VAR using the Akaike's Final Prediction Error criterion. This approach however requires stationary variables, just as standard Granger causality test (as Toda and Yamamoto (1995) shown, the conventional *F*-statistic for the Granger causality test does not have its standard distribution when the time series are integrated). Toda and Yamamoto (1995) method can be used to test the causality even for variables with mixed orders of integration. Essentially the method is based on setting up VAR in levels and augmenting the lag order by the maximum order of integration of the variables. The modified Wald test is carried out for the restriction on the parameters of the VAR(p) where p is the lag length of the system and augmenting the lag order of the VAR to $p + m$, where m is the maximal order of integration of the variables. However, it is crucial the Wald test for restriction of the parameters does not include the coefficients of the "extra" lags, i.e. it restricts only p lagged values of the given variable.

2.4. The Model Setup

In general, the data in levels were transformed to per capita values and then converted to natural logarithms. In case of impulse response analysis, the $I(1)$ variables were transformed to growth rates by taking the first differences (of the natural logarithms).

The methodology adopted for the analysis includes the following steps:

1. Test the stationarity of the variables (e.g. with the augmented Dickey-Fuller [ADF] and Kwiatkowski–Phillips–Schmidt-Shin [KPSS] tests)
2. Identify the maximum order of integration m in the group of variables in the model
3. Test the Granger causality using the Toda and Yamamoto (1995) procedure
4. Identify the basic type of the relationship (neutrality, feedback, growth, conservation.) describing the direction of the causality. Test for the co-integration properties of the variables using the so-called
5. Johansen procedure (Johansen, 1988; Johansen and Juselius, 1990; Johansen, 1991). If the co-integration is found, estimate the VECM. In case of no co-integration, estimate the VAR in differences
6. Estimate the accumulated impulse response function (IRF)[2] from the previous step to determine the sign of the causality.

As for the last step – some studies use the sum of the lagged coefficients of a given variable to determine the sign of the causality. Such an approach, however, may be misleading, as it ignores the dynamic effects between the equations (unlike the impulse responses). Given the nature of the impulse response behavior, we may not be able to produce definite and straightforward answer – the sign can be interpreted in a clear manner, if the response function is positive (or negative) for all periods – in such a case the sign of the causality is positive (or negative).

If the IRF changes its values from positive to negative or *viz*. depending on the time horizon (or the accumulated IRF fades away), then there is no clear-cut sign of causality, as it depends on the time horizon. It should be noted the choice of the IRF may be influential – notably for the so-called Wold-ordering problem.[3] This problem can be overcome by using the so-called generalized impulses, described by Pesaran and Shin (1998), which use an orthogonal set of innovations not dependent on the VAR ordering.

2.5. The Controversy of the Topic

Beaudreau (2010) points out the energy-economy nexus investigation is essentially exploratory in nature and does not have solid theoretical grounding. Despite the effort by Ghali and El-Sakka (2004) to link the topic to the neoclassical production function, it eventually boils down to the description of the dynamic interactions between a set of variables. Due to the "relaxed" position of the theory, the studies differ in their model setup, which renders the comparability of their results rather difficult.

The empirical dichotomy of the results adds to the controversy. There is no consensus regarding the energy-economy causality, not even for the more or less identical samples.

2 The IRF describes the effect of a one-time shock to one of the innovations on the current and the future values of the endogenous variables. The accumulated IRF as the name suggests, represents the cumulative sum of the IRF.

3 The traditional orthogonalized IRF recursively identifies the structural shocks by using the Choleski decomposition of the covariance matrix, which yields a unique lower triangular matrix. This approach however assumes that the first variable in the VAR is contemporaneously uncorrelated with all other variables.

This afflicted the topic from the very beginning. The conclusions of the studies, all regarding the USA data, were switching from the evidence for conservation hypothesis in Kraft and Kraft (1978), to the neutrality hypothesis in Akarca and Long (1980) and back. Yu and Hwang (1984) confirmed the absence of causality using the sample 1947-1979 in the annual frequency, but identified unidirectional causality using the sample 1973-1981 in quarterly frequency. Yu and Choi (1985) and Erol and Yu (1987) concluded their studies with the neutrality hypothesis.

The conclusion of neutrality hypothesis for the USA data can be also found in the subsequent articles by Yu and Choi (1985) and Erol and Yu (1987). Abosedra and Baghestani (1991) however supported the results Kraft and Kraft (1978), despite using different type of tests (direct Granger instead of the Sims' procedure [Sims, 1972]).

Due to the absence of prevailing conclusion, there is a dispute whether the results are spurious. Given the lack of the theoretical basis, it is hard to justify the general validity of the results. The mainstream production theory does not help in the explanation for the role of energy, and there is not even a consensus on the substitutability of energy with the other production factors. The econometric estimates carried out on the industry level come to different conclusions even in the question whether capital and energy are complements or substitutes (Stern, 2004).

The data availability is also an issue. Especially in Europe, with the era of centrally planned economies (CPE) that affected the development of many states. The reasonable assumption on information capability of the past for the current development simply does not hold for but the very recent period in case of post-communist countries. This range may be approximately 20 years or possibly less due to necessary post-transformation adjustments. Given the very limited availability of high frequency data, it is often problematic to set up more complex estimation schemes. Annual data also often lead to the inclusion of rather limited number of lags.

2.5.1. The aggregate and sectoral values distinction

As can be seen in Table 3 majority of the studies employ the macro-level data. This classification is often necessary in heterogeneous country groups due to limited and non-uniform data sources.

However, the results in the studies employing the sectoral distinction (Gross, 2012; Bowden and Payne, 2009; Zachariadis, 2007) indicate the aggregation of the results might prove statistically inefficient and the sectoral data would probably provide a more detailed results. The actual consumption patterns of the sectors exhibit significant differences in the Czech Republic. Therefore, the sectoral distinction is advisable in the estimation. However, the limited data availability again represents a burden.

2.6. The Literature Review Results Regarding the Czech Republic and the Specific Factors of the Czech Energy Sector

So far no study focused on the detailed examination of the energy-economy nexus in the Czech Republic. Some of the studies have, however, included it in their sample. See the contributions by Narayan and Prasad (2008) and Acaravci and Ozturk (2010), using the electricity energy type, Chontanawat et al. (2008) using the thermal aggregate and Menegaki (2011) employing the energy from renewables. While Narayan and Prasad (2008) used the sample period 1960-2002 and have identified growth hypothesis for the Czech Republic, Acaravci and Ozturk (2010), conclude with the neutrality hypothesis for the (whole) examined sample in the examined period 1990-2006. Both these articles utilize the data provided by International Energy Agency. Furthermore, we can observe a similar dichotomy in the results by Chontanawat et al. (2008), who used the thermal aggregate and identify the growth hypothesis relationship (though, similarly as Narayan and Prasad [2008], on the questionable time range of 1971-2000). On the other hand, Menegaki (2011) used the energy from renewables with the time frame of 1997-2007, and concludes with the neutrality hypothesis. We can witness the typical mixed evidence: While studies using the long time period from 1960s or 1970s imply the growth hypothesis causality exists, studies employing only the post-communist era data conclude with the neutrality between the energy and economic activity in the Czech Republic. However, the reliability of the real GDP values for the periods of CPE can be questioned, more so if measured in the US$ 1995 prices (with no reasonably established exchange rate of the currency in these planned economies with heavily restricted currency convertibility).[4] The recent time frame estimates in general show little promise to identify a causal links. Nevertheless, we can see there are many deficiencies in the typical study framework.

2.6.1. Czech energy sector overview

The detailed description of the development of the energy sector in the Czech Republic can be found in Hajko (2014b). In essence, the Czech energy consumption is heavily influenced by more prominent presence of industrial sector in the economy and higher utilization of solid fuels in the energy mix. The Czech energy sector has gone through vast changes since the Velvet Revolution in 1989.

Apart from the overall economic transformation in the Czech Republic in the transition period, the most important changes in the energy sector were opening of the market and the start of the commodity market trading. These events have taken place rather recently (for instance, in case of electricity market, the liberalization process took place gradually during the years 2002-2006, and the electricity market PXE opened in 2007; the natural gas market liberalization process took place in year 2005-2007 (despite that, for households and small consumers, there were little or no supplier shifts until 2009).

Along with the general trend in the world, the prices of all major energy sources have been gradually increasing. The retail price of oil products has risen rather slowly, compared for instance to the prices of natural gas. Despite the natural variations in trends and levels, the common global trend of rising prices of energy

4 Not to mention the claimed data source of IEA (2002) only provides values for the years 1971, 1973, 1978, 1980, 1987, 1988, 1989, and 1990-2000. The values for the centrally planned economies are furthermore marked as estimates.

and the energy commodities can be readily confirmed. The natural gas price development seemingly coincides very well with the liberalization of the market starting in 2005. On the other hand, it should be kept in mind that rather significant rise in natural gas prices can be observed in the gas market in Europe roughly since the same period, though the consumption of the natural gas (or natural gas imports, which is very nearly the same thing in CZ) shows very little changes in the past years.

Despite the market liberalization processes, not all prices are fully market based. The prices of coal (a major energy resource in the Czech Republic) are not regulated, the coal mining has been fully privatized and no financial support for coal production is currently in place. However, it should be noted the coal mines have been privatized without the transfer of re-cultivation costs of closed mines. In the gas and electricity market, the price of the commodity itself is created in the market; however, the prices for the transmission and distribution are regulated. The transmission network is privately owned and maintained. Prices of electricity generated from renewables, combined heat and power generation and secondary energy sources are regulated and declared in the yearly Price Decisions of the regulator (ERÚ). The higher prices for the electricity from the subsidized sources do not enter the market electricity price directly, but are paid by the distribution network operators through the feed-in tariffs. The costs attributed to these payments are then funded by the consumers of the electricity as the special billing added to each kWh of electricity consumed. The electricity prices (especially applicable to the electricity prices charged to households) have been gradually adjusting to the levels common in the neighbor countries, which resulted in a rather steady increasing trend in the electricity price in the last 15 years. The gradual decrease in TPES (an indicator of the amount of energy available in a given country, i.e., energy produced and the export balance) has taken place during the 1990s, with lowest point in 1999. Since 20002, it has more or less stabilized at values around 42-45 MTOE (which is roughly 2.6% of the total TPES in EU-27).

In line with the development in the EU (or most OECD countries in general), the slightly declining share of the industrial sector in the overall balance is taken over by the increasing share of the transportation sector. In retrospective, the comparison of consumption in services shows some significant changes in the energy consumption development of the services, but these changes fall mainly into several years during transformation periods from centrally planned economy. As can be expected, the fuel structure is quite diverse when compared across the economy sectors. We can note some of the typical characteristics, such as the predominant position of oil and oil products in the transport sector and agriculture, forestry and fishing. The natural gas consumption pattern in CZ is roughly the same as in the EU countries. The main difference comes from the higher use of coal in Czech Republic (including for the residential heating). The major consumer of gas is the industrial sector, followed by the residential sector. The industrial sector is also the second largest consumer of oil (after transport). The most significant characteristic of CZ (compared to EU countries) is significantly higher coal consumption - over 11% of the total final consumption, compared to roughly 3% in EU. This is even more prominent in the industrial sector, with roughly a 28% share of its energy consumption (compared to 11% in EU). This higher level of coal consumption is mainly given by the available local resources (so far typically representing a cheaper alternative to other fuels), and historical inertia of existing coal power plants (though gradually declining). This also illustrates that compared to EU countries, oil and oil products' share in the industrial consumption is only about 6% in CZ, while the oil constitutes over 14% of energy consumption in EU).

One of the most heated policy questions (no pun intended) in the CZ however remains the use of the surface mined brown coal. While there are political ambitions to re-establish some of the mining (currently banned by the ecological limits set up in the 1990s) the solution of the issue has yet to be reached. Nevertheless, the transition costs and fuel price change accompanying the switch from coal to other types of fuels might play a role, which on this scale would probably influence the output capabilities of the sector. Currently, the coal is also the major energy export commodity in the Czech Republic, even though the volumes of exports are gradually declining. The import volumes of oil experienced a descent after the Velvet revolution. However, roughly in the past decade, the oil imports have risen nearly back to the levels in 1980s. The increasing economic activity of the transport sector is the main driver behind this increase.

Natural gas supply in CZ is gradually increasing, even though there is some observable volatility and upward trend of retail natural gas prices in the past years. The replacement of coal with gas can be in the long term expected mainly in the space heating (with the district heating plants being most technologically dependent on the brown coal availability). The use of natural gas is mainly in the production of thermal energy, while its share in the production of electricity is only marginal (approximately 5%, mainly in meeting peak electricity demand). The share of natural gas in the overall final consumption experienced gradual increase roughly up to year 2000 and is more or less stable since at around 23%.

Electricity represents around 18% of the total final consumption. Despite the not as large share in the overall consumption, it is the prevailing opinion in the literature that the electricity (as a fuel of high quality), is becoming one of the most important energy types, as well as being trusted with strong hopes for its increasing capability in the transportation sector. Net export volume of electricity has been gradually increasing in the last 15 years in the Czech Republic. Currently the Czech Republic is the second largest net electricity exporter in the EU (after France), with the third largest share of net electricity exports to net electricity generation (after Estonia and Bulgaria). The Czech Republic's net electricity export was approx. 17.12 TWh in 2012 (with roughly 11.58 TWh of imports and 28.7 TWh of exports). In 2011, the electricity generated from renewables in CZ represented approximately 10.3% of the gross electricity consumption (the same indicator was around 20.4% in EU). Approximately 53% of the electricity generation comes from coal and approximately 35% from nuclear heat (Vlcek et al., 2015) for a discussion on future nuclear prospects). As might be expected, electricity consumption is also subject to somewhat influential seasonal fluctuations, especially regarding the residential energy consumption. On the other hand, the industrial electricity consumption is the least influenced by the seasonality. Energy intensity (measured in TOE per thousand 2005 US dollars of GDP calculated using PPPs) was about 0.17 in 2011 in CZ and 0.12 in EU. Both CZ and European aggregate exhibit a downward trend and there is a certain degree of convergence (Hajko, 2012; 2014a for more detailed discussion of Czech and EU energy intensity convergence).

3. METHODOLOGY AND DATA

The quarterly frequency was selected for the data collection. Various data sources were used. The GDP was measured in CZK in chained constant prices and is available from the OECD (2013). The labor (hours worked) and capital (gross stocks of fixed assets) data were obtained from the Czech Statistical Office (CZSO, 2013b,c). The consumer price index (CPI) for the energy products index has the value of the year 2005 = 100 and is provided in the OECD database (OECD, 2013). The final energy consumption data per sector and per fuel are in thousand TOE, and are available from Eurostat (Eurostat, 2013b,c). The electricity consumption per sector (in GWh) is available in the monthly reports of the Czech energy regulatory office, ERÚ (2001-2013). The population totals are available from Eurostat (2013a). The data were transformed to per capita values (except for CPI and price measures), seasonally adjusted, and transformed to natural logs. The total consumption of electricity showed on average 0.81% increase during the examined sample period (2001-2011). The total final consumption and gross fuel consumption were evaluated on the sample 1996-2011. In total values (despite the fluctuations along the way), they remained more or less unchanged, with average −0.5% and 0.05% average annual change. With the GDP, we can record similar values on both samples, amounting to roughly 2.5% (1996-2011) and 2.9% (2001-2011) respectively. The largest relative growth could be observed in the CPI of energy and electricity price, with average annual percentage growth of 6.5% and 5.1% respectively (for aforementioned samples).

3.1. Stationarity of the Variables

In this subsection, the stationarity tests to identify the order of integration are described. Before the stationarity tests were performed, all series were transformed to natural logarithms of their per capita values. If the series represents a percentage or an index, the per capita transformation is not performed. The seasonal adjustment was undertaken for the total employment (hours worked) data and for the electricity consumption data, using the TRAMO/SEATS automatic procedure (Gómez and Maravall, 1996). The determination of the order of integration described here relies on three well established tests - ADF, Phillips-Perron (PP) and KPSS.

ADF test is based on the equation:

$$\Delta y_t = \beta_0 + \gamma t + (\varnothing - 1) y_{t-1} + \rho_1 (\Delta y_{t-1}) + \cdots + \rho_{p-1} (\Delta y_{t-p+1}) + \varepsilon_t \quad (1)$$

This equation is estimated with up to p lags. The test is based on observing whether the coefficient of y_{t-1} is significantly different from zero. The lagged structure for the test was obtained by sequential elimination of insignificant lags (starting from high number of lags), in this article based on the Bayesian information criterion, in order to avoid the problems with possible autocorrelation of the error term in the ADF test equation.

The test proposed by Phillips and Perron (1988) can be viewed as a modification of the ADF test. Unlike the ADF test, it does not rely on addition of the lagged terms. Instead, it relies on the non-parametric Newey and West (1987) correction to compute the standard errors of the test statistic to deal with the potential autocorrelation or heteroscedasticity problems in the test equation. The test proposed by Kwiatkowski et al. (1992) differs from the other unit root tests in the formulation of the null – The series is assumed to be stationary under the null. The KPSS test statistic is based on the residuals from the ordinary least squares (OLS) regression, where the time series in question is decomposed into the sum of a deterministic time trend, a random walk process and a stationary error term.

The test statistic is computed as $KPSS = \sum_{t=1}^{T} \frac{S_t^2}{T^2 f_0}$ where $S_t = \sum_{s=1}^{t} e_s$ is the partial sum of the residuals from the aforementioned OLS regression and f_0 is an estimator of the residual spectrum at frequency zero. In the subsequent tests, the Bartlett kernel-based estimator for f_0 with data-based automatic bandwidth parameter method by Newey and West (1994) was used. The asymptotic critical values can be found in Kwiatkowski et al. (1992). Detailed results of stationarity tests can be found in Table 5. Table 5 the rejection of null at 5% level of significance is indicated by an asterisk. The order of integration is determined by taking the differences of the variable and re-testing for the presence unit root – the order of integration therefore indicates the number of differences necessary to obtain a stationary series. There are two instances (final energy consumption in transport sector, and gross consumption of natural gas), where the tests do not provide clear cut decision whether the order of integration is 0 or 1 – So in these two cases, the order of integration is marked as 1(!), to be on the safe side. In cases of dichotomous test results regarding the non-stationarity, the visual examination of the series is advisable. Capital stock data and the final and fuel-specific energy consumption data from the Eurostat were available only in the annual frequency, so the necessary adjustment to the higher frequency had to be performed.

The complex investigation of the idea of ideal transformation of low frequency to high frequency data can be found in the literature (either described as the interpolation for the stock data, or temporal disaggregation for the flow data). The reason for the use of temporal disaggregation or interpolation is to use the information contained in the original high frequency series, instead of discarding it. As discussed in Pavía-Miralles (2010), in cases when some of the relevant series are only available at lower frequencies, the improvements in the model selection, efficiency of the estimates and the prediction quality are usually improved if the frequency of the original (typically annual) time series is increased. The univariate methods, proposed by Boot et al. (1967) or Stram and Wei (1986) are useful, if there is no additional information available (complimenting the original

Table 5: Stationarity test results

Name	ADF *P* values	PP *P* values	KPSS test statistic	ADF *P* values, in differences	PP *P* values, in differences	KPSS test statistic, in differences	Order of integration
GDP	0.858	0.888	0.972*	0.016*	0.016*	0.158	1
Labor	0.391	0.398	0.497*	0.000*	0.000*	0.086	1
Capital stock	0.956	0.950	0.912*	0.000*	0.000*	0.252	1
CPI for energy	0.189	0.157	0.989*	0.000*	0.000*	0.405	1
Total final energy consumption	0.707	0.535	0.154	0.235	0.002*	0.117	1
Final energy consumption in agriculture	0.000*	0.000*	0.823*	0.068	0.013*	0.314	0
Final energy consumption in industry	0.599	0.492	0.797*	0.018*	0.000*	0.081	1
Final energy consumption in other	0.022*	0.084	0.514*	0.000*	0.000*	0.044	1
Final energy consumption in residential	0.270	0.386	0.517*	0.105	0.013*	0.133	1
Final energy consumption in services	0.244	0.460	0.428	0.216	0.000*	0.228	1
Final energy consumption in transport	0.325	0.019*	0.935*	0.468	0.000*	0.560*	1(!)
Electricity price	0.945	0.928	0.799*	0.000*	0.000*	0.199	1
Total electricity consumption	0.250	0.250	0.319	0.000*	0.000*	0.215	1
Electricity consumption in industry	0.158	0.170	0.155	0.000*	0.000*	0.108	1
Electricity consumption in transport	0.790	0.804	0.664*	0.000*	0.000*	0.106	1
Electricity consumption in construction	0.447	0.402	0.236	0.000*	0.000*	0.270	1
Electricity consumption in agriculture	0.150	0.232	0.720*	0.000*	0.000*	0.305	1
Electricity consumption in residential	0.002*	0.001*	0.276	0.000*	0.000*	0.272	0
Electricity consumption in services	0.156	0.170	0.173	0.000*	0.000*	0.249	1
Electricity consumption in other	0.002*	0.002*	0.666*	0.000*	0.000*	0.500*	0
Total gross fuel consumption	0.324	0.470	0.339	0.004*	0.004*	0.175	1
Gross fuel consumption of solid fuels	0.896	0.491	0.582*	0.031*	0.000*	0.050	1
Gross fuel consumption of natural gas	0.485	0.541	0.601*	0.120	0.102	0.297	1(!)
Gross fuel consumption of nuclear heat	0.623	0.713	0.887*	0.031*	0.027*	0.150	1
Gross fuel consumption of petroleum	0.431	0.611	0.664*	0.673	0.002*	0.269	1
Gross fuel consumption of renewables	1.000	0.995	1.003*	0.121	0.000*	0.181	1

*Indicates the rejection of the null hypothesis (ADF and PP null hypothesis: Unit root; KPSS null hypothesis: no unit root). ADF: Augmented Dickey-Fuller, KPSS: Kwiatkowski–Phillips–Schmidt-Shin, PP: Phillips–Perron, GDP: Gross domestic product

series). Their results are, however, often very similar to standard methods of interpolation, such as the cubic spline interpolation. This is the case of the energy consumption data from Eurostat. The multivariate methods use related series (one or more) to capture the high frequency development, while adhering to the constraint represented by the original (typically annual) values of the original series. Examples of these methods are Chow and Lin (1971); Fernandez (1981); Litterman (1983) or Santos Silva and Cardoso (2001). It should be noted, that with long-standing effort and nearly a decade of improvements the Matlab routines to handle most of these methods were published by Quilis (2009). In the estimates, the Litterman (1983) procedure has been employed for the Capital stock data, with the use of quarterly series of gross fixed capital formation (CZSO, 2013a) as a high frequency indicator (in the literature, the gross capital formation is often used as a proxy for the capital stock changes, with the assumption that if the depreciation rate is constant, the variance in capital is mostly related to the changes in investment [Jin and Yu, 1996; Shan and Sun, 1998; Sari and Soytas, 2006; 2007; Narayan and Smyth, 2008; Apergis and Payne, 2010]). To avoid the influence of exchange rate fluctuations when employed along with the data for GDP (OECD, 2013), the Czech National Bank exchange rate data (ČNB, 2013) were used to adjust the capital stock figures.

4. RESULTS

4.1. The Aggregate Models

The results from the models employing aggregate energy consumption data are shown in Tables 6 and 7. In Tables 6 and 7, the models B1, B2 and B3 label the bivariate estimates. Models F1, G1, H1 are the "standard" multivariate specifications (i.e., with the inclusion of the capital and labor). F2, G2 and H2 are the multivariate specifications with the additional endogenous variable representing the CPI of the energy products. The inclusion of the price measure is desirable in all aggregate energy variable specifications. In the literature review section it was shown only four of the studies included the price measure. Of these four, however, only Gross (2012) included energy-oriented price measure, while the other authors settled for the general CPI.

Unlike these studies, the more relevant indicator has been employed as the energy price measure. Specifically, the CPI for the energy products was used in the models regarding the final and fuel specific consumption, while the retail electricity price was used for electricity consumption models. The comparison of the models with and without the omission of the price variable therefore indicates the neutrality of energy and GDP might be based on ignoring more complex channels through which the energy manifests its influence. Unlike what seems to be the prevailing opinion in the literature, the production function alone (explaining the addition of the measures of capital and labor) is not capable to capture this influence.

The models based on the final energy consumption or fuel specific consumption do not exhibit causal relationships, unless the multivariate approach with the price measure has been employed (as we will see in the following text, this typically holds also for the sectoral or fuel-specific consumption models). In general, we can find the evidence for the conservation hypothesis with the positive

Table 6: *P* values of the Wald tests for causality testing in aggregate models

Description	Model designation	Lag order	Number of co-integration relationships	Wald test for causality *GDP→E*	Wald test for causality *E→GDP*
Final energy consumption, bivariate	B1	1+2	0	0.616	0.215
Final energy consumption, multivariate without price	F1	1+4	1	0.252	0.915
Final energy consumption, with price	F2	1+2	0	0.704	0.057
Electricity consumption, bivariate	B2	1+2	1	0.182	0.000*
Electricity consumption, multivariate without price	G1	1+2	0	0.013*	0.000*
Electricity consumption, multivariate with price	G2	1+2	2	0.239	0.000*
Fuel specific consumption, bivariate without price	B3	1+2	0	0.524	0.22
Fuel specific consumption, multivariate without price	H1	1+1	0	0.331	0.266
Fuel specific consumption, multivariate with price	H2	1+1	0	0.167	0.084

*Indicates statistical significance at 5% level, GDP: Gross domestic product

Table 7: The results of models using aggregate energy consumption data

Model designation	Energy variable	Causality type	Sign of the causality
B1	Final energy consumption	Neutrality hypothesis	N/A
F1	Final energy consumption	Neutrality hypothesis	N/A
F2	Final energy consumption	Conservation hypothesis	+
B2	Electricity consumption	Conservation hypothesis	+
G1	Electricity consumption	Feedback hypothesis	+/+
G2	Electricity consumption	Conservation hypothesis	+
B3	Fuel-specific consumption	Neutrality hypothesis	N/A
H1	Fuel-specific consumption	Neutrality hypothesis	N/A
H2	Fuel-specific consumption	Conservation hypothesis	+

sign in all types of aggregate consumption models. In other words, the increasing economic growth is expected to increase the energy consumption (no matter if measured as the final energy consumption, electricity consumption or consumption of fuels). The positive sign of the hypothesis would advocate the possibility of energy conservation plans, without the penalty in the form of output-inhibiting effects. However, it also means the consumption of the energy is expected to rise with the increasing economic development.

4.2. The Sectoral Models

4.2.1. Sectoral consumption – final energy consumption

Tables 8 and 9 provide the results of models employing final energy consumption data. Surprisingly enough, in most cases the individual consumption of a sector does not seem to form a strong enough causal relationship with the overall economic performance. As such, the neutrality hypothesis does not help with the selection of any specific sector as the most "promising" (in terms of curbing the expected rise in energy demand with increasing economic level). On the other hand, it can be also viewed as the foundation for the claim that conservation policy action might be implemented in any sector.

The important exception is the industrial energy consumption (model K2). In this model, the general expectations related to the rather industry-oriented Czech economy environment seem to correspond well with the model results, indicating the "special" position of the industry in the Czech economy. The expectation of economic growth projecting onto the industrial energy consumption would then favor the implementation of energy efficiency and/or conservation in the industrial sector. The multivariate specification without the energy price on the other hand does not identify the causal link in the industrial sector, but the negative conservation hypothesis relationship in the service sector.

Despite the possible uncertainty of the result (given the apparent neutrality of the industry in the multivariate framework without the price variable), from the viewpoint of the energy policy, both cases are not an issue for a conservation implementation.[5] Nevertheless, given the results of the previous section, it seems reasonable to favor the specification with the inclusion of the price variable, and as such, the industrial sector seems to be the most favorable target of the energy conservation schemes.

4.2.2. Sectoral consumption - Electricity consumption

Tables 10 and 11 summarize the results of models employing electricity consumption data. Again the story seems to be quite well-corresponding to the overall picture from the previous estimations. The causal links can be identified predominantly with the industrial energy consumption. This link seems to be quite robust, as it holds for all of specifications. As in the previous case of final energy consumption, the electricity consumption seems to be influential in the services in the multivariate specification without the energy price. While it is identified with the negative sign, the direction of the causality would seem to be reversed, constituting the growth hypothesis. Alongside with the fuel specific consumption of the RES, these are the only cases of the growth hypothesis. The negative sign of the causality in the

5 Because this would indicate that with the higher economic growth, the energy consumption of the services will be reduced (this might be the case if, with the higher economic level, the services are becoming more hi-tech and less input intensive - As might be the case with information technology related services, or more knowledge-based activities). The special attention would be required for possibly higher energy consumption in the periods of recessions. But we can also recall the share of energy consumption in the sector, which would indicate the relatively low impacts of the increase on the overall energy position in the Czech Republic, rendering the optional special policy attention as the relatively low-priority one.

Table 8: *P* values of the Wald tests for causality testing in sectoral models with final energy consumption

Description	Model designation	Lag order	Number of co-integration relationships	Wald test for causality *GDP→E*	Wald test for causality *E→GDP*
Final energy consumption, bivariate					
Agriculture	C1	1+2	0	0.506	0.491
Industry	C2	1+2	0	0.84	0.434
Other	C3	1+2	0	0.357	0.768
Residential	C4	1+2	0	0.64	0.899
Services	C5	1+4	2	0.756	0.544
Transport	C6	1+2	0	0.475	0.304
Final energy consumption, multivariate, without price					
Agriculture	J1	1+2	1	0.134	0.816
Industry	J2	1+4	2	0.815	0.772
Other	J3	1+1	0	0.214	0.781
Residential	J4	1+4	1	0.219	0.409
Services	J5	1+4	4	0.195	0.068
Transport	J6	1+2	0	0.734	0.544
Final energy consumption, multivariate, with price					
Agriculture	K1	1+3	1	0.273	0.919
Industry	K2	1+3	1	0.997	0.003*
Other	K3	1+1	1	0.418	0.965
Residential	K4	1+2	0	0.648	0.848
Services	K5	1+4	2	0.278	0.169
Transport	K6	1+2	0	0.77	0.584

*Indicates statistical significance at 5% level, GDP: Gross domestic product

Table 9: The results of models using final energy consumption

Model designation	Energy variable	Causality type	Sign of the causality
Final energy consumption, bivariate			
C1	Agriculture	Neutrality hypothesis	N/A
C2	Industry	Neutrality hypothesis	N/A
C3	Other	Neutrality hypothesis	N/A
C4	Residential	Neutrality hypothesis	N/A
C5	Services	Neutrality hypothesis	N/A
Final energy consumption, multivariate, without price			
J1	Agriculture	Neutrality hypothesis	N/A
J2	Industry	Neutrality hypothesis	N/A
J3	Other	Neutrality hypothesis	N/A
J4	Residential	Neutrality hypothesis	N/A
J5	Services	Conservation hypothesis	-
J6	Transport	Neutrality hypothesis	N/A
Final energy consumption, multivariate, with price			
K1	Agriculture	Neutrality hypothesis	N/A
K2	Industry	Conservation hypothesis	+
K3	Other	Neutrality hypothesis	N/A
K4	Residential	Neutrality hypothesis	N/A
K5	Services	Neutrality hypothesis	N/A
K6	Transport	Neutrality hypothesis	N/A

case of electricity consumption in services would indicate that the lower consumption of energy would contribute to the faster economic growth. This might happen if the consumption was associated with the change in the types of the services towards the less energy intensive or more value added oriented ones. Typically, this would be associated with the IT or knowledge-based services. The electricity consumption is often considered to be the energy type most closely related to the energy-economy nexus. This expectation seems to be supported by the results for CZ, with causality being found in all specifications on the aggregate level, and with industry link identified in all specifications on the sectoral level.

As in the previous case, the probably most favorable setup is in the multivariate framework with the price measure. Apart from the industry, we can record a positive sign conservation hypothesis relationship in the transport sector. In the Czech Republic, the transport seems to be growing in the importance in the late years, even with some suppression of the dominant position of the industry. The results indicate we can expect the increase in the consumption of electricity in the industry and transport sectors with increasing economic development. Attempts to curb the energy consumption might therefore be best suited to these two sectors. Given the results of the previous settings (with final energy consumption), the industrial sector seems to be especially viable choice for the implementation of the energy policy measures.

4.2.3. Fuel specific consumption

The results of models with fuel-specific consumption are provided in Tables 12 and 13. The bivariate models show no causal links. The multivariate scheme without the price measure speaks for the growth hypothesis causality (along with the electricity consumption in the services), but this time with the positive sign. The usual implication for this type of relationship is that the energy reduction plans should not be implemented in the given area, as it might lead to lower economic growth. Or, rather in agreement with various RES advocates, that the energy consumption of RES

Table 10: *P* values of the Wald tests for causality testing in sectoral models with electricity consumption

Description	Model designation	Lag order	Number of co-integration relationships	Wald test for causality *GDP→E*	Wald test for causality *E→GDP*
Electricity consumption, bivariate					
Industry	D1	1+2	1	0.659	0.037*
Transport	D2	1+2	0	0.687	0.257
Construction	D3	1+2	0	0.932	0.943
Agriculture	D4	1+2	0	0.703	0.647
Residential	D5	1+2	0	0.68	0.345
Services	D6	1+2	0	0.729	0.83
Other	D7	1+2	0	0.779	0.828
Electricity consumption, multivariate, without price					
Industry	L1	1+1	0	0.655	0.000*
Transport	L2	1+2	0	0.707	0.184
Construction	L3	1+1	0	0.358	0.689
Agriculture	L4	1+2	0	0.789	0.246
Residential	L5	1+1	0	0.172	0.106
Services	L6	1+1	1	0.055	0.404
Other	L7	1+2	0	0.736	0.931
Electricity consumption, multivariate, with price					
Industry	M1	1+4	3	0.621	0.000*
Transport	M2	1+3	4	0.833	0.000*
Construction	M3	1+1	1	0.394	0.323
Agriculture	M4	1+2	1	0.451	0.928
Residential	M5	1+1	0	0.323	0.428
Services	M6	1+2	2	0.218	0.323
Other	M7	1+4	3	0.439	0.566

*Indicates statistical significance at 5% level, GDP: Gross domestic product

Table 11: The results of models using electricity consumption data

Model designation	Energy variable	Causality type	Sign of the causality
Electricity consumption, bivariate			
D1	Industry	Conservation hypothesis	+
D2	Transport	Neutrality hypothesis	N/A
D3	Construction	Neutrality hypothesis	N/A
D4	Agriculture	Neutrality hypothesis	N/A
D5	Residential	Neutrality hypothesis	N/A
D6	Services	Neutrality hypothesis	N/A
Electricity consumption, multivariate, without price			
L1	Industry	Conservation hypothesis	+
L2	Transport	Neutrality hypothesis	N/A
L3	Construction	Neutrality hypothesis	N/A
L4	Agriculture	Neutrality hypothesis	N/A
L5	Residential	Neutrality hypothesis	N/A
L6	Services	Growth hypothesis	-
L7	Other	Neutrality hypothesis	N/A
Electricity consumption, multivariate, with price			
M1	Industry	Conservation hypothesis	+
M2	Transport	Conservation hypothesis	+
M3	Construction	Neutrality hypothesis	N/A
M4	Agriculture	Neutrality hypothesis	N/A
M5	Residential	Neutrality hypothesis	N/A
M6	Services	Neutrality hypothesis	N/A
M7	Other	Neutrality hypothesis	N/A

should be increased in order to boost economic growth. However, we can observe that this type of causality disappears if the energy price variable is included in the estimation scheme.

As such, it seems fallacious to recommend the increased RES consumption (especially if we recall the fact the prices for the RES energy are declared by the regulatory office [and thus do not bear a meaningful response to consumer demand], and this increased cost is in turn diluted into the retail energy prices). Instead, in the more complex framework including the energy price variable, the RES and nuclear energy show neutrality with the economic growth. On the other hand the solid fuels and natural gas exhibit conservation hypothesis relationship but with the opposite signs. The significance of the solid fuels is unsurprising. The expectation of the increasing consumption of the solid fuels with the economic growth seems to be an indicative of possible problems, if there is a sharp decline in the coal supply (as might be the case, if the environmental limits stay in place). As such, the energy policy targeted at the energy conservation should consider the solid fuels as its main target fuel in the energy conservation plans. Incidentally, this is in line with the other target plan of lower emissions or various other plans to lower the environmental pollution. While the EU energy-related environmental policies target primarily on the reduction of the CO_2 emissions, the environmental impacts especially in the local consumption areas, can be more pronounced from the other types of emissions, many of which are especially pronounced with the coal).[6] Contrary to

6 Such as the sulfur and nitrogen oxides, or various mercury compounds (Pacyna et al., 2003; 2010) and the various types of ash (see e.g. Carlson and Adriano, 1993 for the review), toxic slurry from the flue-gas desulfurization processes, or in certain cases the formation of polychlorinated dibenzodioxins (Everaert and Baeyens, 2002).

Table 12: *P* values of the Wald tests for causality testing in sectoral models with fuel specific consumption

Description	Model designation	Lag order	Number of co-integration relationships	Wald test for causality *GDP→E*	Wald test for causality *E→GDP*
Fuel specific consumption, bivariate					
Solid	E1	1+2	0	0.398	0.267
Nuclear	E2	1+2	2	0.856	0.628
Natural gas	E3	1+2	0	0.602	0.283
Petrol	E4	1+2	0	0.776	0.368
RES	E5	1+2	0	0.633	0.84
Solid	E1	1+2	0	0.398	0.267
Fuel specific consumption, multivariate, without price					
Solid	N1	1+2	0	0.894	0.125
Nuclear	N2	1+2	1	0.561	0.39
Natural gas	N3	1+2	0	0.593	0.465
Petrol	N4	1+3	2	0.392	0.958
RES	N5	1+1	0	0.077	0.667
Solid	N1	1+2	0	0.894	0.125
Fuel specific consumption, multivariate, with price					
Solid	O1	1+4	0	0.503	0.087
Nuclear	O2	1+4	1	0.855	0.273
Natural gas	O3	1+5	0	0.663	0.043*
Petrol	O4	1+6	2	0.051	0.018*
RES	O5	1+1	0	0.435	0.176
Solid	O1	1+4	0	0.503	0.087

*Indicates statistical significance at 5% level. GDP: Gross domestic product

Table 13: The results of models using fuel specific consumption data

Model designation	Energy variable	Causality type	Sign of the causality
Fuel specific consumption, bivariate			
E1	Solid	Neutrality hypothesis	N/A
E2	Nuclear	Neutrality hypothesis	N/A
E3	Natural gas	Neutrality hypothesis	N/A
E4	Petrol	Neutrality hypothesis	N/A
E5	RES	Neutrality hypothesis	N/A
Fuel specific consumption, multivariate, without price			
N1	Solid	Neutrality hypothesis	N/A
N2	Nuclear	Neutrality hypothesis	N/A
N3	Natural gas	Neutrality hypothesis	N/A
N4	Petrol	Neutrality hypothesis	N/A
N5	RES	Growth hypothesis	+
N1	Solid	Neutrality hypothesis	N/A
Fuel specific consumption, multivariate, with price			
O1	Solid	Conservation hypothesis	+
O2	Nuclear	Neutrality hypothesis	N/A
O3	Natural gas	Conservation hypothesis	-
O4	Petrol	Feedback hypothesis	±
O5	RES	Neutrality hypothesis	N/A
O1	Solid	Conservation hypothesis	+

RES: Renewable energies

the possible expectations (especially regarding the future position of natural gas in the [world] energy balance) the results show the inclination to the decreasing natural gas consumption with the economic development (or to be more precise, with the higher GDP growth per capita). This is somehow atypical result, but we should also recall the fact that lately the Czech prices of natural gas exhibited rather significant upward trending, despite the stagnating import volumes.

From the energy conservation viewpoint, this might be an important result if we take into the account the opposite signs of the conservation hypothesis causalities for the natural gas and the solid fuels. From the energy conservation viewpoint, it might be beneficial to lend support to the substitution of the natural gas and the coal. The consumption of petroleum and petroleum products exhibits a bidirectional causality, but with incongruent signs. The positive sign of causality from GDP to petroleum consumption indicates there is a higher demand for petroleum products if the economy is growing. This would indicate the petroleum and petroleum products are intermediate products and the increased consumption is the result of increased demand for goods and services. On the other hand, the negative sign of causality from petroleum consumption to GDP might be caused by two reasons. The first one might be an indication of the increasing proportion of the relatively less productive (or more energy-intensive) activities in the economy (this would typically be the case, if we could observe the rate of energy consumption growth higher than the GDP). Or, given the fact the gross consumption has been employed, it might also be caused by capacity constraints, distribution losses or increased inefficiencies in the fuel chain. In such a case, the increased consumption would primarily be that of the energy sector. Due to the relatively stable technological background, the reasoning attributing the result to the increasing losses is doubtful. The breakdown of the industrial consumption in Hajko (2013) shows there is no inclination towards higher energy intensity.

5. CONCLUSION

The objective of this article was to identify the appropriate type of the energy-economy nexus in the Czech Republic, employing variety of model specifications. The results provide a rather strong indicative for the conservation hypothesis in the Czech Republic, with the positive sign of causality. In other words, the increasing economic growth exhibits a causal tendency to increase the energy consumption.

The methodology proposed in this article uses the modified Wald tests, proposed by Toda and Yamamoto (1995) to determine the direction of the causality. To decide on the sign of the causality, the accumulated generalized impulse responses have been used (the co-integration testing was performed to determine the appropriate VAR or VECM form).

The inclusion of the sign analysis seems to be beneficial in the estimation interpretation.[7] Furthermore, the changing outcome of some of the signs depending on the specification speaks for the price measure inclusion in the model specification, as the outcomes of a "typical" recommendation might be quite the opposite (if the negative sign of the causality is present). The inclusion of the energy-related price measure is beneficial to proper identification of the causality. The influence of the energy-price induced changes on the other production factors is strong enough to change the outcome of the causality tests in several cases. This also shows the production function theoretical basis is not sufficient *per se*. The overall policy recommendation for the Czech Republic is the plausibility of the application of energy conservation policies. The neutrality hypothesis is the most prevailing hypothesis, implying the energy conservation might be implemented without the additional penalty of economic slowdown.

The most appropriate hypothesis to define the policy framework is the conservation hypothesis in the usual form – i.e., the energy consumption is expected to rise as a consequence of economic growth. This implies the conservation policies should be adopted and the energy conservation policies will not impose a penalty in terms of lower economic growth. The total final energy consumption seems to be causally influenced by the changes in the economic activity. Apart from the industrial sector, it is hard to identify other sectors that would seem to contribute to the aggregate result. As such, the primary target of the conservation should probably be the most influential sector, i.e. the industrial sector. This result holds with the electricity consumption as well, the attention should be focused on the industry along with the transport sector. Comparison of the models differentiated by the inclusion of the price variable in the estimation framework indicates the neutrality of energy and GDP might be based on ignoring more complex channels through which the energy manifests its influence. In the multivariate framework with the price variable, the aggregate consumption of the final energy, gross fuel consumption or electricity consumption all show the evidence for the conservation hypothesis in the traditional form (with the positive sign). The industrial sector seems to deserve the most attention from the energy conservation targeted policy. The prevailing role of the energy therefore seems to be in line with its characteristics of intermediate goods, that is manifested especially through the increased energy demand in the industrial sector and this holds for both the final energy consumption and the electricity consumption specifications. The electricity consumption results also show quite reasonable correspondence of the sectoral and aggregate results to the increasing share of the transport sector in the recent years alongside the industry. With the evidence for the conservation hypothesis, the indication of the growing consumption of energy in industry and transport sectors speaks for the attention paid to the industry in order to fulfill the goal of the energy consumption reduction. Nevertheless, the prevailing evidence for the neutrality hypothesis does not preclude the application of the energy conservation measures in other sectors. The fuel specific consumption confirms the importance of the solid fuels consumption in the Czech economy (note that solid fuels are the main differentiating factor between the Czech and the European fuel mix compositions). With the increasing economic performance, we might expect increasing pressure on the intermediate demand for the solid fuels (the likely reason is the significant presence of the solid fuels in the Czech industrial energy mix). This, along with the aforementioned results and the fact the electricity generation is based heavily on the solid fuels, speaks for the favorableness of the reduction in the consumption of solid fuels. Unlike the popular opinion, the consumption of RES or nuclear heat is nowhere as important in the energy-economy nexus as the other types of fuels, namely solid fuels, natural gas or petroleum products. The empirical causalities are found with a positive sign. This corresponds well to the usual expectation in the hypotheses formulations – this, however, might not always be the case. The comparison of several model results indicates the conclusions of studies without the sign consideration might be insufficient. However, we should also note the fact that the negative signs are (with one exception regarding the petroleum consumption) all found in the specifications without the energy price measure. The linkage between the price and consumption in the response computation seems to be significant. As the electricity seems to be an important part of the energy-economy nexus in the Czech Republic, there seems to be a strong incentive for the energy policy attempts to reduce the consumption of the solid fuels.

7 This holds especially if the energy variables are not examined only in the aggregate values.

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