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The Granger causal relationship between energy consumption and economic growth for eight European countries

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Abstract: Motivated by the rising importance of today's environmental issues and more specifically the role of energy conservation policies, the current study investigates the Granger causal relationship between energy consumption and economic growth in eight European countries. Using a large dataset that overall spans from 1800-2009 the study employs the Toda-Yamamoto procedure and cointegration analysis with and without structural breaks in order to specify the Granger causality between the two variables both in a historical perspective but also more recently, after the third Industrial Revolution. The main focus is placed on the effect that energy conservation policies could potentially have on the growth potentials of each country.

The results, clearly suggest that historically the relationship between energy consumption and economic growth is not neutral for all countries, while in some cases there is evidence that energy conservation policies could actually be a threat to economic growth. More importantly though, it is found that the relationship between the energy consumption and economic growth has changed after the 1970s suggesting that today's energy conservation policies can actually be in line with a more environmentally sustainable growth pattern in most countries. The only exception is the arbitrary case of Portugal where a causal relationship from energy consumption to economic growth could still be in place.

Key words: Economic growth, energy, Granger causality

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1. Introduction[1]

Energy has historically been the foundation of economic growth since it always constituted one of the basic inputs in the process of both social and economic development. There are various driving forces that simultaneously may affect the demand for energy consumption while at the same time the availability of energy and energy security are key determinants of economic activity and growth (Yoo and Lee, 2010). The constant population growth, the increasing urbanization processes underway mostly in developed economies but also the intense industrialization of some major developing countries are some of the factors that may affect the energy patterns. However, at the same time, the current environmental concerns draw the attention in new ways of conceptualizing economic growth and inevitably energy consumption. Particularly in the case of the European Union, which is considered to be a global forerunner in the deployment of sustainable development strategies, understanding the energy- growth nexus is of outmost significance. This is essential in order to design and implement effectively energy and environmental policies that will not only tackle current environmental threats but will at the same time favor the prospects of each country's economic growth potentials.

The role of energy in economic growth is to a great extend stressed and researched by ecological and resource economists that tend to hold a relatively critical attitude towards the neoclassical way of conceptualizing the economy. As Stern (2004) argues, most business and financial economists, seeing energy as an unlimited factor, tend to focus more on the impact of oil and other energy prices on the economy rather than the role of energy consumption and of other resources. In neoclassical economics the amount of energy consumed in economic activities is considered to be endogenous and consequently it is not considered as a driver of economic growth and production. On the contrary, for ecological economists the main idea of the role of energy as a production factor is based on the two thermodynamic laws, especially the second one of entropy, and on the very fact that in any production process a minimum amount of energy needs to be consumed (Zachariadis, 2007). In simple terms, ecological economists treat energy as limited resource.

In this respect, the role of energy in economic activity is highly debated while the relationship between energy consumption and economic growth although been researched by various researchers no consensus has yet been reached. The vast literature that examines the role of energy in an economy and more specifically the interplay between energy and economic growth has mainly started to develop after the oil crisis of the 1970s and was primarily focusing on the effect that energy prices had on economic activity (Kraft and Kraft, 1978). According to Stern and Enflo (2013), the most commonly used methods to examine the "causal" relationship between the two factors are through Granger causality and cointegration analysis. These methods have been used by most studies that have attempted to address the relationship between the two variables while different tests and procedures have been applied in each study.

1.1. Research topic and research question

That being said, in the current study a time series analysis will be employed in order to examine the Granger causality between energy consumption, and economic growth (measured

[1] Part of the information included in this section has been taken from the final paper written by Theodoridis (2013) for the course EKHM44 Advanced Time Series Analysis.

through GDP) in eight developed economies. A special focus will be placed in the relationship between energy consumption and economic growth after 1970 since it is expected that a different long-run pattern could have immerged with the introduction of the third Industrial Revolution and the breakthrough of information and communication technologies (ICT revolution). The argument is based on Warr and Ayres (2012: 93) who starting from the structural change of the 1970s argue that "future economic growth will be increasingly driven by the information and communication technologies" as they will constitute a significant input to growth also driving improvements in energy productivity.

The countries that will be examined are England, France, Germany, Italy, the Netherlands, Portugal, Spain and Sweden. Employing a time series with more than 200 observations (ranging somewhere between 1800-2009 depending on the country under study), these countries were mainly selected based on data availability since for a reliable time series analysis an adequate number of observations should be available (the generally admitted minimum being around 40 observations). Being one of the few studies that actually use such a lengthy dataset, the results of the current study are expected to shed some more light on the findings of previous studies that have examined the relationship. At the same time, they will extend the already existing research by examining the relationship between energy consumption and economic growth before and after 1970. Consequently, the research questions of the study can be formulated as follows:

> *"What is the Granger causality between energy consumption and economic growth in the long run?*
> *Does the relationship between energy and economic growth change after the 1970s?"*

At this point it needs to be mentioned that it is acknowledged that the results will be somewhat limited by the fact that a bivariate model with only energy consumption and real GDP is used and consequently a more rough estimation of the relationship of energy and growth is suggested. In reality the energy- growth interplay is more complex while there are also several policies through which the environmental impact on growth can be reduced (Stern, 2004). Energy may affect economic growth through various channels, operating as an input for other factors of production such as labor and capital. As argued by Stern and Enflo (2013) there is an advantage of using multivariate models to test Granger causality since it is possible to minimize the probability of reaching to spurious correlations by adding more explanatory variables in the models. Nevertheless, historical data availability (from 1800 and 1850) hampers the inclusion of more variables in the constructed models of this study.

In what follows, section two provides the relevant theoretical background of the study focusing on the implications of the interplay between energy and economic activity and states the hypothesis that will be tested. Additionally, results of previous studies in the field are reviewed in this section. In section 3, the data that are used are presented and a preliminary analysis is conducted. In section 4 the methodology that is followed to conduct the time series analysis analysis is explicitly discussed. In section 5 the key findings are presented and analyzed. Finally, section 6 concludes with the main findings and a broader discussion on the obtained results.

2. Theory[2]

2.1. Theoretical background and hypothesis

The relationship between energy and economic growth has been examined by various researchers from different perspectives. Conventional (neoclassical) economic theory, based on the argument that energy holds a relatively marginal cost share in an economy's production (not historically but more recently), compared with capital and labor, suggested that there is a neutral relationship between energy consumption and economic growth (Warr and Ayres, 2010). However, according to Zachariadis (2007), some researchers examine this relationship within an extended neoclassical framework where they try to explore the interplay of energy with other production factors as well as its role in technological progress and productivity changes. Additionally, Toma and Jemelkova (2003), try to identify relationships between energy and growth by focusing on the developments of energy. In particular, they take under consideration measures of the availability of energy, energy quality as well as energy resources and check in what way are they associate with economic development in lower income countries. Furthermore, another study by Warr and Ayres (2010) on the US, makes a distinction between energy quality (efficiency of energy use) and energy quantity (by measuring exergy- useful work) in order to better identify its relationship with growth.

Generally, concerning the interplay that characterizes energy and economic growth, in the case that we consider energy demand as a function of economic output, the following formalization has been proposed by Medlock and Soligo (2001):

$$E_{jt}=f(Y_{jt},p_{jt},\tau(Y_{jt},p_{jt}))$$

where energy consumption at time t for each economic sector j is a function of the economic output (Y), the price of the energy (p) and the technology available (τ). Accordingly, according to Stern (2000), economic output is a function of the usual production factors (capital (K) and labor (L) but also of energy consumption (E):

$$Y_{jt=}\ f(K_{jt},L_{jt},E_{jt}(p_{jt})$$

As argued by Stern and Enflo (2013), Granger causality testing has been the approach used by most studies that try to identify the "causal validity" of energy-output models. Granger- causality implies causality in a sense of predicting the outcome rather than in a more structural sense and is mainly based on the idea that "the future cannot cause the past" (Chontanawat et al. 2008: 211). It is based on the concept of causal ordering, meaning that two variables could be correlated by chance but only if X can actually cause Y, in a philosophical sense, could the past values of X be used to predict the levels of Y (Stern and Enflo, 2013). In a more formal way, a variable X is said to Granger cause another variable Y if past values of X help predict the current level of Y given all other appropriate information (Asteriou and Hall, 2011).

One of the main reasons for examining the "causal" relationship between energy and growth is to actually determine the role of energy in an economy. Of course energy is important and as David Stern argues, "we know that energy is used to produce things and we know that in theory income is a

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[2] Part of the information included in this section has been taken from the final paper written by Theodoridis (2013) for the course EKHM44 Advanced Time Series Analysis.

determinant in the demand function for energy". However, this is not always found when analyzing the data given that the relative importance of energy as a driver of economic growth may change. Gales et al. (2007) argue that if energy is crucial for an economy in the sense that growth cannot occur without it, then shortages in its availability could put in danger the growth prospects of the country. On the contrary, in the case that a decoupling between the two variables is found then one can be more optimistic about a country's economic future. More specifically, after econometrically identifying the mechanisms that determine the interplay between energy consumption and economic growth, one can assess the impact of policies that target to decrease environmental degradation. In particular, if for instance a relationship between energy and growth is found and runs from energy to growth, then this could imply that policies which target to decrease energy consumption, as part of a national environmental strategy, are likely to affect the country's economic growth. As argued by many researchers (Chinatnawat et al. 2006, 2008; Lee, 2006; Masih and Masih, 1998; Stern, 1993, 2000; Zachariadis, 2007), such a finding indicates that the economy under study is highly energy-dependent and consequently it provides strong evidence that the environmental policies which aim at reducing CO_2 emissions and energy consumption could in fact affect negatively the growth potentials of a country. It is an indication that energy efficiency improvements through technological innovations have not been so much developed and consequently economic activity is relatively less energy efficient.

Following the same line of thought and in order to stress the significance of these studies, Lee (2006) refers to the Kyoto Protocol, which came into force in 16 February 2005 and based on which most developed countries are bounded to decrease their CO_2 emissions in the coming years relative to the levels reported in 1990. Within such a policy framework, understanding the relationship of energy and growth is very important. A thorough understanding could indicate the relative position that each country should hold and the kind of policies it should adopt. In the case of unidirectional causality from energy to growth, energy consumption cuts (in order to decrease CO_2 emissions) could actually harm the economic activity of a country. In the opposite case where the relationship runs from production to energy, the economy's growth may not be halted by energy conservation policies. In fact, such a case could even imply that energy conservation policies are required as economic activity develops so that a sustainable growth pattern can be achieved (Lee, 2006).

Additionally, conclusions can potentially be drawn depending on the causality found and the policies that are already employed by various countries. For example, the hypothesis that countries like Sweden, the UK and Germany may put more emphasis on such energy conservation policies because no significant energy-growth relationship exists can be tested. More specifically, if for instance it is found that economic growth in some countries is not so much, or not at all, affected by energy consumption then this fact could potentially make it easier for them to adopt energy conservation policies (Zachariadis, 2007). This finding could potentially justify the adoption of such policies by these economies since they do not constitute a threat to their prospects for economic growth.

All of the above mentioned relationships that could potentially exist between a country's energy consumption and economic growth make explicit the testing of four different hypotheses. In general Payne (2009), after examining the literature on the topic, identifies four distinct hypotheses for the relationship between energy and growth and these are the ones that will also be tested in the current study. These are the "growth hypothesis", the "conservation hypothesis", the "neutrality hypothesis" and the "feedback hypothesis".

According to the first hypothesis, energy consumption is assumed to contribute to economic growth both directly, as well as indirectly through other factors of production such as capital and labor. In fact, the presence of unidirectional Granger causality running from energy consumption to economic growth provides support for this hypothesis.

Concerning the “conservation hypothesis”, it is expected for an economy that unidirectional causality will run from GDP to energy consumption. The support of this hypothesis could more generally imply that energy conservation policies would not adversely affect real GDP. On the contrary, and given the direction of causality, energy conservation policies should be encouraged and promoted in order to frame the consequences that economic activity could have.

Regarding the third- “neutrality hypothesis”- as mentioned earlier, in a sense it could reflect the neoclassical conceptualization of energy in an economy’s production. Hence, it is hypothesized that there is no Granger causality between the variables implying that energy consumption serves very little in the explanation of changes in the GDP series.

Finally, the last hypothesis that can explicitly be tested relates to the bivariate relationship between energy and growth. It is called “feedback hypothesis”, meaning that simultaneously changes in energy consumption patterns may affect an economy’s GDP and vice versa. Evidence that would provide support for this relationship would suggest that both variables are endogenous to a country’s general economic system and single equation forecasts could in reality prove misleading yielding biased results (Lee, 2006).

2.2. Previous research

There are a lot of studies that have examined the “Granger causality” between the two variables however no consensus has yet been reached. Regarding the previous research on countries also examined in the current study, these have mainly been performed with datasets significantly smaller than the one employed here. In one of the first studies in the field, Erol and Yu (1988) find that for the period 1950-1982 no Granger causality is found in the case of France while for Italy in the same period causality from GDP to energy consumption is found. In the study by Chontanawat et al (2008) the researchers conduct an analysis on 108 countries and find that there is a long-run relationship between the two variables only for 12 countries. This could be because the time period examined is relatively small and consequently such a small number of observations may affect the validity of the results. Additionally, the results of a previous analysis by Chontanawat et al (2006) for the same group of countries suggests that causality between energy and GDP is more commonly found among Organization for Economic Cooperation and Development (OECD) countries than least developed economies. As regards the direction of causality, it is found that for 57% of the developed countries, causality runs from GDP to energy while for the non-OECD economies this energy-growth relationship was found for 47% of the group. More specifically for the countries examined here, during the period 1960-2000, bidirectional “causality” is found for France, Germany, Italy and Portugal while unidirectional causality from GDP to energy is found in the cases of Spain and Sweden. For England no causal relationship is noticed between the two variables while Netherlands is the only country for which causality runs from Energy to GDP (Chontanawat et al. 2006). Another recent study by Vaona (2012) for Italy is one of the few studies that examine the relationship between the two variables in the long-run employing a dataset that spans from the mid-1800s. After distinguishing energy consumption between renewable and non-renewable energy, the study concludes that there is bidirectional causality between non-renewable energy consumption and output while no Granger causality was found between renewable energy and output. As regards Sweden, the recent study by Stern and Enflo (2013) mainly employs multivariate models in order to thoroughly investigate the relationship between energy and output in different sample periods that span from 1850-2000. However, the estimation of a simple bivariate energy-GDP VAR model suggests that causality runs from GDP to energy consumption in the whole period (1850-2000).

Additionally, it needs to be noted that a review of previous studies in the field, included in Chontanawat et al. (2006), also suggests ambiguity in the sense that the results of causality differ significantly among studies on the same country. As Zachariadis (2007) and Stern and Enflo (2013) argue, in some cases there are noticed differences between studies that have analyzed the same countries and have used relatively similar datasets, due to the different methods that are followed. For instance, Soytas and Sari (2003) employ an error correction model and find causality for Germany and France running from energy to economic growth while the results obtained from Lee (2006) using a different method- the Toda and Yamamoto procedure, suggest for Germany that there is no relationship between energy and economic activity while in the case of France the completely different causal relationship is found (from GDP to energy consumption). Additionally, in the case of Netherlands, the study by Lee (2006) finds a unidirectional causality that runs from energy consumption to GDP, a finding that is accordance with those of Chontanawat et al. (2006, 2008).

From what has been said, it becomes obvious that the results prove to be extremely sensitive to the length of the period that is examined, the tests and estimation methods that are employed as well as the variables that are used (multivariate or bivariate models). As stated by Stern and Enflo (2013), the techniques that are employed are very sensitive to variable definition, choice of additional variables (for instance energy prices) and the use of appropriate structural breaks. Consequently, the interpretation of the results needs to be done with great cautiousness, while the policy and economic implications that are drawn should be considered under the limitations imposed by the abovementioned factors.

3. Data[3]

In order to address the research question of the Granger causality between energy and economic growth, various variables have been used to measure both terms. In terms of energy, in most studies data of energy consumption are used while in some cases diversification might exist depending on data availability. More, specifically, different energy forms have been examined separately and in accordance with the sector that uses it (industrial, residential and transportation energy consumption of coal, oil and electricity) (Zachariadis, 2007). Regarding growth, usually real GDP is used but also GDP per capita and data on employment have been used as relevant proxies to measure economic development. Also in some studies like Stern and Elflo (2013), a quality adjusted index of energy is used as this has been proposed by Stern (1993, 2000).

Regarding the dataset upon which the current study is built, this includes energy (denoted as "E") and real GDP time series for the England, France, Germany, Italy, Netherlands, Portugal, Sweden and Spain that overall cover the period from 1800-2009[4].

The energy data are expressed in Pj (Petajoule) while GDP is expressed in real 1990 International Dollars PPP so that it allows for comparisons between the two countries and can be useful in the analysis. Both variables are expressed in their totals so that valid relationships can actually be established. In fact, in the literature that examines the relationship between energy and economic activity, wrong operationalization of the variables has been noticed. Some researchers, when analyzing the Granger causality between energy and growth may for instance construct a bivariate model with total energy consumption and GDP per capita. Although econometric analysis such as Granger causality does not require a priory any solid theoretical background, the variables need to measure the same thing so that valid inferences can be drawn. Consequently, in such cases of mismatch the results of the study will tend to be misleading and will not provide useful and meaningful information.

The historical energy consumption refers to primary energy carriers, including the traditional carriers. Additionally, it needs to be mentioned that although the data are provided in absolute values, in this study they are transformed into their natural logarithms. A double-log functional form will be used since it is more convenient to interpret the estimated coefficients. In particular, in a double log specification, a 1% change in the independent variable (X) is associated with $\hat{\beta}$% change in the dependent variable (Y). In other words, the estimated coefficients can be interpreted as elasticities. Given that GDP and energy consumption grow in a percentage change and follow a non-linear trend, by taking the natural logarithms of the series we can reach a linear relationship.

Regarding the number of observations that are used, it is generally admitted that the larger the number of observations the more consistent the results of the study will be. In particular, in his study Zachariadis (2007) uses 7 developed economies in order to examine the relationship between energy and growth while three different tests are used to specify the Granger causality between the two variables. The results of the study are consistent among the methods only for the case of US, where data are available for a relatively longer time period (he uses traditional Granger causality with ARDL model, Toda and Yamamoto procedure and VEC model). More importantly, when

[3] Part of the information included in this section has been taken from the final paper written by Theodoridis (2013) for the course EKHM44 Advanced Time Series Analysis.

[4] The dataset has been kindly provided by Professors Astrid Kander, Paolo Malanima, Paul Warde, Maria del Mar Rubio and Ben Gales and PhD Sofia Henriques. The data will also be included in the forthcoming study by Kander et al. (2013).

reducing the number of observations to a 40-year period, the results vary significantly among the different methods.

In the current study, as mentioned before the dataset overall covers a period of almost 200 years. In detail, for Sweden, Netherlands and England, the period of study will be the bigger since it will span from 1800-2009 corresponding to 209 observations. In the case of France, GDP data constrain the analysis to the period 1820-2009 (189 observations). Additionally, regarding Germany, Spain and Portugal the period from 1850-2009 will be covered, which corresponds to 159 observations. Finally, Italy is the country with the least number of observations since there is available information only from 1861 and onwards. Overall, even though there are these “limitations” for some countries, the data that will be used provide enough observations compared to most of the studies that examine the relationship between energy and growth. The number of observations still exceeds by far those of previous studies that were based on bivariate models and this is expected to provide more reliable results.

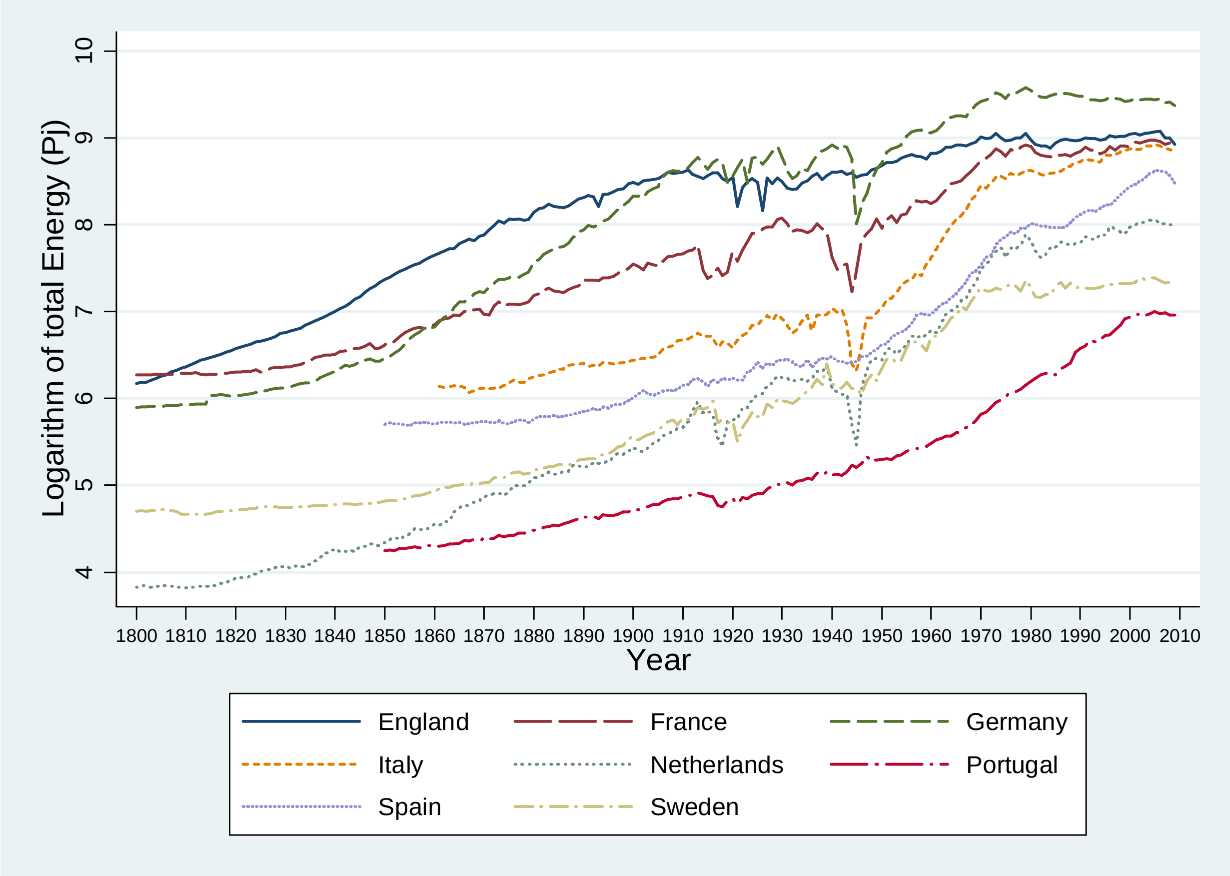
3.1. Preliminary data analysis

In order to better understand the properties of the variables that are used, and more importantly get a better feeling of the energy and economic patterns that the countries followed, it is necessary to provide an ocular inspection of the energy and real GDP series. However, it is also useful to provide a brief and general presentation of the energy and economic pattern that Europe as a whole followed in the period examined.

Evidence from Kander et al. (2013) suggests that during the 20th century, in Europe the increase in energy consumption was much faster than in the 19th century. In fact two clear phases of expansion are identified with the first taking place during the second Industrial Revolution (1870-1910) and the second between the years 1950- 1970. The first period was characterized by intense economic integration that resulted in a boost in both energy and GDP while a second phase of integration (“globalization period” in Europe) is also responsible for the “unparalleled” spurt in energy consumption and economic growth Kander et al. (2013). Overall, in their study, when examining the period 1870-2000 as whole, it is suggested that the use of energy in Europe increased sevenfold.

In Figures 1 and 2, the logarithmic series of total energy consumption and real GDP are presented for all eight European countries. From a first ocular inspection it can easily be argued that none of the series (both those of energy consumption and those of real GDP) seem to be stationary but they rather follow a pattern of “random walk”. Generally, in stationary time series, the shocks will have a temporal effect since over time they will tend to be eliminated and the series should return to their long-run mean values (Asteriou and Hall, 2011). Even though this is not a surprising finding for the data that is used here, it is necessary to employ formal tests in order to identify the properties of the variables in a more reliable way. More in detail information regarding these formal tests are presented in the following method section.

Figure 1. Total energy consumption series for eight European countries, 1800- 2009



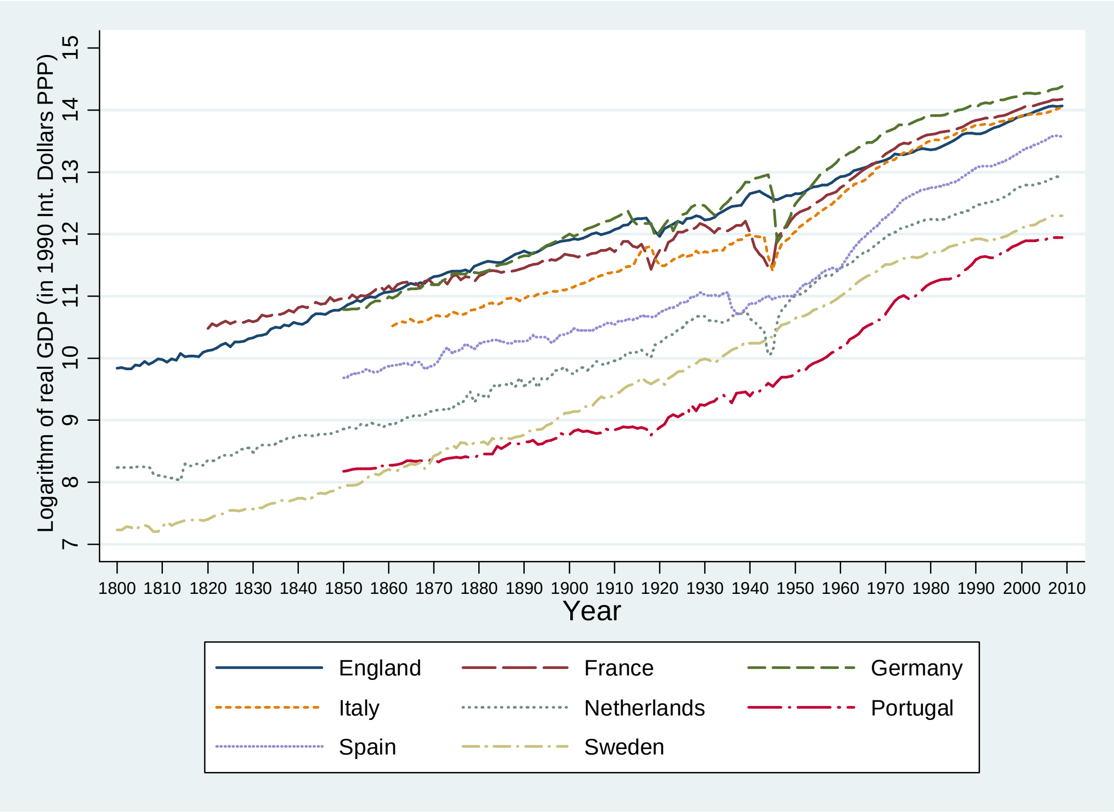
Source: own calculations based on data from Kander et al (2013)

In Figure 1, the historical evolution of total energy consumption for all eight countries is presented. For the cases of England, Germany and the Netherlands the increase in total energy consumption seems to represent much closer the general pattern that characterized Europe during the period 1850-1910. In fact, during the second half of the 19th century up until the First World War, energy consumption increased dramatically and was mainly driven by the intense industrialization process that was under way in these economies. On the contrary, the pattern for the rest of the countries in the sample is somewhat different. In particular, for France, Sweden and Portugal a relatively smoother increase took place in the same period while Spain and Italy are characterized by a modest change in total energy consumption. Furthermore, regarding the following period from 1910-1950, all eight countries present a relatively stable long-run pattern. However, this is "interrupted" by short-run fluctuations, mainly caused by major events such as the financial crisis of 1929/30 and the Second World War. Regarding the second phase of expansion in Europe (1950-1970), an unparalleled spurt in energy consumption characterizes almost all the economies and is mainly part of the so called "Golden Age" that Western European countries had entered . The only exception is the case of England where a relatively modest increase is noticed.

Finally, after 1970 the long- run upward trend of energy consumption is halted for most European countries. It is acknowledged that one of the reasons could be the dramatic price increases in energy that followed the oil crises of 1973/74 and 1979/80. However, the relatively strong and permanent effect in the energy consumption pattern that is noticed in the graph (spanning up until the recent years) could also suggest something different. In particular, a stronger and probably more convincing argument is that this change in the trend could more closely be associated with the third Industrial Revolution (ICT revolution) that took off after the mid-1970s and changed ever since the relationship between the two variables. As seen from Figure 1, for most countries, a more stable pattern seems to characterize energy consumption until the recent years while for the cases of Germany and England, the consumption levels prior to 1970 are never reached again. It needs to be noted though that for the "European South" a different pattern applies. In fact, for Spain and Portugal the upward trend that characterized the period 1950-1970 is continued right after the price shocks. The oil crisis seems to have extremely temporary effects and energy consumption continues to increase rapidly to reach a breaking point in the end of the 2000s.

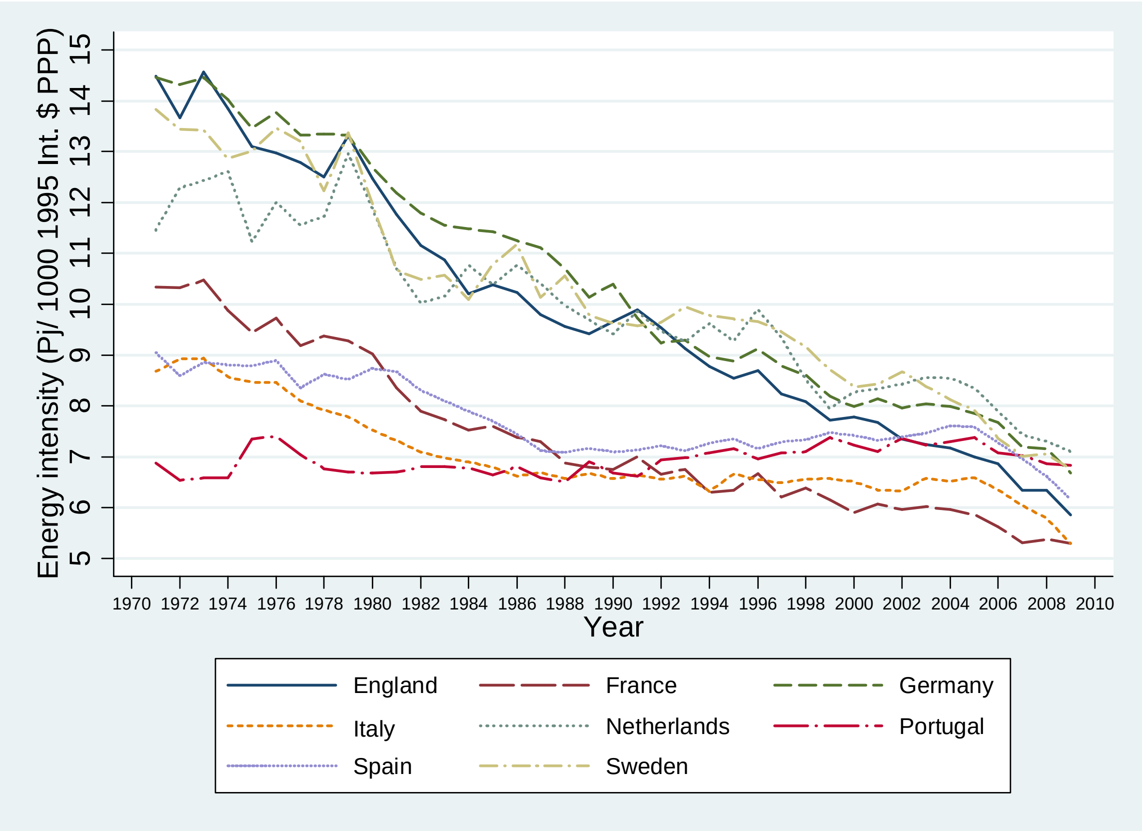
Regarding the historical economic development of the eight countries, in Figure 2 the natural logarithms of real GDP series are presented. All economies follow a relatively stable long-run growth pattern that spans from the 19th century until the First World War. The interwar period is somewhat different among the countries. In detail, for Portugal, Sweden and the Netherlands, the upward trend of real GDP is not halted while in the case of Spain, a sudden drop in the GDP occurs in the mid-1930s and is probably associated with the civil war and the uprising of Franco's dictatorship in the country. Concerning Italy, France, Germany and England, they demonstrate relatively more turbulent fluctuations in GDP in the short-run. During the "Golden Age" (1950-1970) GDP increased dramatically in all countries under study following the upward path of energy consumption. Finally, the effects of the oil crisis in the 1970s, in contrast with energy consumption, are not clearly reflected in any of the GDP series. Although for some countries like Germany, France and Italy (due to their role and size in Europe) the rate of growth has somewhat decreased, all economies continued to expand after 1970 until the recent years.

Figure 2. Real GDP series for eight European countries, 1800- 2009



Source: own calculations based on data from Kander et al (2013)

Figure 3. Energy intensity for eight European countries, 1970- 2009



Source: own calculations based on data from Kander et al (2013)

This finding suggests a decoupling between energy consumption and economic activity providing support to the argument that after 1970, the relationship between the two variables could have changed. The hypothesis seems to be stronger for most countries while for the cases of Spain and Portugal a coupling between the two variables could still hold even after 1970s given that the two variables continue to rise simultaneously. In fact, in Figure 3 the energy intensities (the ratio of energy consumption to GDP) of all countries after 1970 are presented and it can clearly be seen that while for the majority of them energy intensity declines, suggesting a decoupling between the two variables in the long run, for Spain and more clearly for Portugal the ratio remains relatively stable at the same levels, after 1970. This could be attributed to the relatively latter industrialization that the countries had compared to the more developed economies in northern Europe. In fact, the study by Henriques (2011) on the Portuguese economy has shown that two key outcomes of the later industrialization of the country could be the main reasons for the existing coupled relationship of energy consumption and economic growth after 1970. The first is related with the "subsectoral structural change" that occurred in the country which was relatively different than that of more advanced economies in Europe favoring the immergence of energy intensive industries like chemicals and pulp. However the second and more "concerning" factor, has been the fact the country's industry after the 1970s was focused more on a low value added production structure. In this sense, "in an time where knowledge was the important factor of production, producing low value- added products could … compromise the decoupling of energy from economic growth" (Henriques, 2011: 256).

Following the same line of thought, regarding the potential change in the relationship between energy consumption and economic growth, Warr and Ayres (2012) argue that from the early 1970s until the late 1980s the resources' prices rose sharply for the first time setting in this way the basis for the emergence of a new way of thinking economic growth and the role of energy resources in it. Additionally, the relative importance of energy as a driver of economic activity and growth may have changed as the developed countries have shifted their production structure away from energy intensive industries towards less energy intensive economic sectors (Warr and Ayres, 2010). However, Henriques and Kander (2010) have shown that the share of the service sector in the developed economies is characterized by a rather modest increase. The key determinants of changes in the energy intensity of these countries have mainly been technological innovations which increased productivity or were within- sector changes in industry that have resulted to lighter subsectors of production (Henriques and Kander, 2010). Finally, Warr and Ayres (2012) also argue that useful work (exergy) and information (promoted by the ICT revolution) seem to have become of greater significance as drivers and determinants of economic growth compared to more traditional production factors such as labor and capital. This potential change will be examined more in the time series analysis part of the study.

Table 1. Average annual growth rate of total energy consumption and real GDP in eight European countries (in percentages)

	1800-1849	1850-1913	1914-1945	1946-1975	1976-2009
England					
GDP	1.90	2.17	1.29	2.44	2.25
Energy	2.39	1.90	-0.03	1.41	-0.12
France					
GDP	1.63[a]	1.46	-1.08	6.41	2.15
Energy	0.97	1.85	-0.93	4.41	0.41
Germany					
GDP	-	2.53	0.76	7.35	1.82
Energy	1.10	3.66	-2.41	4.81	-0.24
Italy					
GDP	-	1.84[b]	-0.23	6.32	2.18
Energy	-	1.18[c]	-1.34	7.35	0.80
Netherlands					
GDP	1.20	1.99	-0.01	6.73	2.44
Energy	0.97	2.60	-1.57	7.20	0.79
Portugal					
GDP	-	1.13	2.05	4.69	3.02
Energy	-	1.10	0.91	2.76	2.74
Spain					
GDP	-	1.51	0.94	5.54	3.00
Energy	-	0.84	0.60	4.81	1.81
Sweden					
GDP	1.39	2.58	2.51	4.27	2.01
Energy	0.20	1.71	0.67	3.93	0.03

[a] The average growth rate refers to the period 1820-1849 given that data on GDP are available only after 1820
[b] The average growth rate refers to the period 1861-1849 given that data on GDP are available only after 1861
[c] The average growth rate refers to the period 1861-1849 given that data on Energy are available only after 1861
Source: own calculations based on data from Kander et al (2013)

Overall, based on what has been seen from the Figures 1, 2 and 3 presented above, the period that is examined can be divided in four different sub periods as they are presented in Table 1. The periodization as well as the growth patterns, bears a lot of similarities with that in the study of Vaona (2012) which examines the relationship between energy and GDP for Italy. The estimations of the average growth rates of both energy and GDP in different sub-periods provide support to the previous analysis of Figures 1 and 2. In fact, the coupled relationship between energy and growth during the industrialization period, the interwar period and the “Golden Age” are clearly illustrated for most of the countries. More importantly though, the argument that after the oil crisis the relationship between energy and growth changed (de-coupling) is strongly supported by the findings in Table 1. Especially for the cases of Germany and England, this change in the relationship between the two variables is even stronger. Although the average growth rate of the economy was positive (1.82 and 2.25 respectively), energy consumption followed a completely opposite pattern of a small negative average growth rate per annum. Finally, the findings in Table 1 also support the strong exception of Portugal (probably and Spain) as a case where after the 1970s a strong relationship between energy and economic activity continues to hold. More specifically, the relatively high average economic growth rate of almost 3% in Portugal is accompanied by a similarly high average annual growth rate of energy consumption (approximately 2.7%).

4. Method[5]

4.1. Unit root test

Before proceeding further in the analysis, it is essential to test formally for the properties of the series that are used in this study. For this reason, the real GDP as well as the energy consumption series of all the countries will be tested for the presence of a unit root or in other words to check for stationarity and their order of integration. For this reason, the augmented Dikey-Fuller (ADF) and Phillips-Perron (PP) tests will be used to test for unit root. The tests will be conducted at a 5% significance level. Consequently, for the variables in log levels the following regression is estimated.

$$\ln Y_t = \alpha + \beta t + \gamma \ln Y_{t-1} + \varepsilon_t \qquad (1)$$

In equation (1), Y will take the values of real GDP and energy consumption for each country respectively. Additionally, the stationarity tests will be conducted both in the whole period where data is available for each country but also for the sub-periods; beginning time of each country until 1969 and from 1970 until 2009. This is necessary in order to proceed further in the analysis and adequately address the research questions. The null hypothesis for both tests is that the series contain a unit root; H_0: $\gamma=1$. Additionally, it needs to be noted that as seen from equation (1), a time trend is included in the specification which will be removed based on its significance at the 5% significance level.

Additionally, it is essential to mention that the main problem with the unit root tests is that they have a low power. In other words, there is decreased ability to reject a null hypothesis when it is actually false. To make the argument even more specific, in the case of testing for stationarity with the ADF and PP tests we may falsely conclude that there is a unit root even if there was not one. For this reason, in order to control for Type II errors the series will also be tested based on the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test for stationarity. The test can be conducted under the null hypothesis of either trend stationarity or level stationarity.

Concerning the lag structure that is used in the model of each series and for each country, a testing down procedure will be followed in order to determine the number of lags. First we start by an ocular inspection using a correlogram of the series in order to get a feeling on the dependence that exists with past values of the variable. Additionally, it needs to be noted that when deciding upon the lag structure, the number of observations that we have should also be considered. With relatively smaller samples, a higher order of lags, although it may not affect the size of the test, it could decrease its power increasing the chances of conducting a type II error (Perron, 1989). Fortunately though, the sample size of the current study is relatively big and may not suffer from such problems. In the case of the sub-samples that the number of observations will be decreased the lags will be treated with caution.

Finally, the specification with the number of lags that is reached needs to be tested for autocorrelated residuals. In order to test for autocorrelation the Breuch- Godfrey LM test for serial correlation will be used. Although the presence of autocorrelation may not affect the OLS estimators severely since they will remain unbiased, they will no longer be efficient. Autocorrelation may affect

[5] Part of the information included in this section has been taken from the final paper written by Theodoridis (2013) for the course EKHM44 Advanced Time Series Analysis.

the variance of the estimated coefficients and consequently the testing of hypothesis may not be valid (Asteriou and Hall, 2011). In case of serially correlated residuals, the model will be re-specified by adding more lags of the variable tested until no autocorrelation is found.

Regarding structural breaks, it is worth mentioning that their inclusion is important when testing for the presence of unit root. In fact, Perron (1989) demonstrated that failure to allow for structural breaks, actually reduces the ability of the simple tests (like the ADF test) to reject the null hypothesis of unit root when this is in reality false. In other words, the tests that do not incorporate structural breaks are suffering from loss of their power. For this reason the series will also be tested for the presence of unit root by employing two different tests. However, these tests are applied only in the whole period of each country given that the sub-periods have a relatively smaller span that does not require that much the use of structural breaks.

Primarily, the Zivot and Andrews (1992) (denoted ZA) unit root test will be used. The test was developed as an extension of Perron's (1989) unit root test where the structural breaks were exogenously determined. Perron's (1989) test is based on a modified version of the traditional augmented Dickey-Fuller test where a dummy variable is used in order to account for one know structural break that is chosen independently of the data. However, in order to avoid what has been called "data mining", when the break is a priori determined, Zivot and Andrews (1992) developed a unit root test that endogenously determines one structural break in the series at the point where the t-statistic of the ADF test takes its maximum negative value. In other words it could be argued that the break date is chosen at that point in time when it is more probable to reject the null hypothesis of unit root. In this study Perron's Model C will be adopted to perform the ZA unit root test since it allows for a break both in the intercept ("crash") as well as the trend ("changing growth"). Borrowing the notation used in Glynn et al. (2007), the model for testing unit root in its general form is

$$X_t = \alpha_0 + \alpha_1 DU_t + d(DTB)_t + \gamma DT_t + \beta t + \rho X_{t-1} + \sum_{i=1}^{p} \Phi_i + \Delta X_{t-1} + e_t \qquad (2)$$

Where TB is the time of the break and DU_t is the dummy used for a break in the intercept; DU_t=1 if (t>TB) and DU_t=0 otherwise. DT_t stands for a change in the slope of the trend where DT_t=t-T_t for t>T_t and 0 otherwise. Regarding the crash dummy, (DTB)=1 if t=TB+1 and zero otherwise (Glyn et al. 2007). The null hypothesis that is explicitly being tested is that the series contain a unit root and the alternative is that the series is a trend stationary process with a possible break at an unknown point in time (Zivot and Andrews, 1992).

One of the main drawbacks of the ZA test, as it has been stressed by Lee and Strazicich (2003), is that it does not assume a break under the null hypothesis and consequently, it derives its critical values accordingly. Consequently, a "rejection of the null hypothesis does not necessarily imply rejection of a unit root per se but would imply rejection of a unit root without breaks" (Lee and Strazicich, 2003: 1082). Furthermore, this possible divergence of the t-statistics could also lead to a biased rejection of unit root, when there actually exists one. For this reason, in order to account for more than one break points in the series and make the unit root analysis more robust, the Lee and Strazicich (2003) unit root test will also be employed using the RATS statistical software. The minimum Lagrange Multiplier (LM) unit root test endogenously determines two structural breaks both in the intercept ("Crash") as well as the intercept and trend ("Break"). This test procedure is also based on Perron's models A and C and allows for two endogenous breaks both under the null (unit root) and the alternative (stationarity) hypothesis. In the study we follow Stern and Enflo (2013) and employ the Lee and Strazicich's "break" model for the log series in levels (alternative hypothesis is trend stationarity with breaks) and the "crash" model for the log differenced series (alternative hypothesis level stationarity with breaks).

4.2. Granger causality testing

Traditionally, older studies that examined the relationship between two variables tested Granger (non)causality, using the Granger (1969) test, by estimating a VAR model in levels and by using a Wald test in order to test the linear restrictions on the parameters of the model. However these studies did not use to take under consideration the properties of the series such as stationarity and cointegration relationships (Asafu- Adjaye, 2009). This method has proved to be wrong since in case the series are non-stationary and integrated, then the t-statistics do not follow a chi-squared distribution and consequently the test does not work properly. More specifically, the Wald test statistic does not follow the usual asymptotic chi-square distribution under the null hypothesis and consequently does not allow for valid estimations of Granger causality.

Because of the problems that emerge when the properties of the series are not taken under consideration and because unit root test is generally considered to have low size and power properties when applied in small samples, there has been an increasing use of methods which do not require that the variables are pre-tested for their level of integration or cointegration. Other methods have been developed which allow the use of a VAR model in levels even if the series' properties are unknown. Hypothesis tests can successfully be carried out with these methods irrespective of whether the variables involved are stationary or not and regardless of the existence of a cointegrating relationship among them (Masih and Masih, 1998).

One of these methods is the Toda and Yamamoto (1995) procedure (denoted T-Y) that will be used in the current study and involves a modified Wald test in an augmented vector autoregressive (VAR) model. As stated by Toda and Yamamoto (1995) in their popularized article, it is possible to test for general restrictions in the parameter matrices of a VAR model using the usual chi-square critical values no matter whether the VAR is integrated of arbitrary order or the series are cointegrated. In more detail, following the T-Y procedure, primarily a VAR in levels is constructed while in order to decide upon the lag length of the model, the Schwartz information criteria (BIC) will be consulted since it is suggested that it provides better results for bigger samples like the one employed here. Additionally, the Jarque-Bera and Breuch-Godfrey LM post estimation tests will be performed in order to tests the normality and autocorrelation of the residuals respectively. In case that there are problems with the residuals, the VAR model will be re-specified by including more lags. Finally, more lags of all the variables will be included according to the higher order of integration of the series. It needs to be noted though that these lags are included as exogenous variables in the system and consequently they do not affect the computation of the Wald statistics and the Granger causality test[6]. In detail, the VAR model that is estimated for each country is the following:

$$Y_t = \alpha_0 + \sum_{m=1}^{k} \alpha_{1m} Y_{t-m} + \sum_{j=k+1}^{k+d} \alpha_{2j} Y_{t-j} + \sum_{m=1}^{k} \gamma_{1m} E_{t-m} + \sum_{j=k+1}^{k+d} \gamma_{2j} E_{t-j} + \varepsilon_{1t} \quad (3)$$

$$E_t = \beta_0 + \sum_{m=1}^{k} \beta_{1m} E_{t-m} + \sum_{j=k+1}^{k+d} \beta_{2j} E_{t-j} + \sum_{m=1}^{k} \delta_{1m} Y_{t-m} + \sum_{j=k+1}^{k+d} \delta_{2j} Y_{t-j} + \varepsilon_{1t} \quad (4)$$

Where Y and E correspond to real GDP and energy consumption respectively while *α, β, γ* and *δ* are coefficients to be estimated. The *k* lag length is selected based on the Schwartz information criteria

[6] Detailed steps of the Toda and Yamamoto (1995) procedure can be found in Prof. David Giles blog: http://davegiles.blogspot.se/2011/04/testing-for-granger-causality.html

and the post-estimation checks while *d* is equal to the maximum order of integration of the two series. The Granger causality test is performed after performing a Wald test on the coefficients γ_{1m} and δ_{1m} (for *m=1,..,k*).

At this point it needs to be mentioned that in order to explicitly address both parts of the research question, the procedure will be applied in both the whole sample but also in two subsamples for all eight countries; the first includes the beginning year of each country until 1969 and the second spans from 1970 until 2009. In this way it will be possible to check whether the relationship between economic activity and energy consumption has changed after the 1970s.

Finally, in order to ensure the robustness of the results, the procedure will also be applied after including structural breaks in the model. In particular, the methodology presented by Stern and Enflo (2013) will also be employed here where exogenous breaks are included in both the intercept and the trend[7]. In detail, when examining the whole period in each country but also the first sub-period (until 1970), two break points will be included. The first break year will be in 1914 corresponding to the First World War while the second is in 1950 related with the beginning of the "Golden Age" in Europe. As regards the second sub-period (from 1970-2009), it is considered relatively small and one could argue that the inclusion of structural breaks is unnecessary. However, in order to be consistent and ensure the robustness of the results, only one break will be included in the year 1980 so that it accounts for both energy crises of the 1970s[8].

4.3. Cointegration analysis

The main drawback of the standard Granger test, as mentioned before, is that it is necessary to apply a "differencing filter" to the variables which in most cases tend to be non-stationary (Masih and Masih, 1998). In this way, although the series will behave well in a statistical sense, by differencing them we essentially remove any of the long-run information which may exist between them and which can be of great importance for policy implications. As argued by Masih and Masih (1998; 1288), "an additional channel of causality emanating from any long-run co-movements the variables may share" could exist.

For this reason a cointegration analysis will also be conducted in order to test the relationship between energy and economic growth in the long run. According to Engle and Granger, (1987), if cointegration is found between two variables then there must be Granger causality between them- either unidirectional or bi-directional relationship. In this way, the cointegration test also provides a possible cross-check on the validity of the results that are found with the Toda and Yamamoto procedure. The key point of cointegration is that if there really is a "genuine" long run relationship between energy and growth, then despite the fact that both energy and growth are rising over time, there will be a linear combination between the two variables. In other words it is examined whether there really exists a long-run "equilibrating force" that characterizes energy consumption and economic activity which does not allow the two variables to "drift apart" in time (Giles, 2011).

In order to test for cointegration, the Johansen (1988) and Johansen et al. (2000) cointegration test will be followed by both using and not using structural breaks. However, it needs

[7] For more detailed presentation of the model see Stern and Enflo (2013: 12) equation N° 5.

[8] The year of 1980 is also suggested as a break point by the ZA and LS unit root tests for most countries and for both variables in this period. The tests were conducted separately to help identify a break year and their results are not included in this study.

to be noted that the cointegration test and subsequent analysis (estimation of VEC model) will only be performed in the total period for which data is available in each country. It is acknowledged that the cointegration test could also be applied in the two sub-periods before and after 1970. Nevertheless, the limited number of observations in these two periods (especially in the later; 1970-2009) is not expected to yield reliable results regarding the cointegration of the two series. This may also affect a valid and consistent cross checking with the results of the Granger causality obtained from the Toda and Yamamoto procedure. As mentioned earlier, in other studies there have been noticed inconsistencies between the results of the T-Y procedure and the Johansen test that mainly arise from the limited number of observations available in the latter (Zachariadis, 2007). Additionally, it needs to be noted that because the Johansen test is extremely sensitive to the sample size, the results of the test will be tested both at the 5% as well as the 10% significance level.

It should be noted that in order to perform the Johansen test all our variables need to be I(1), something that will be determined by the unit root and stationarity tests. Furthermore, in order to decide upon the lag length that will be used in the tested equation, a VAR in levels will be specified after consulting the information criteria. In particular, again the Schwarz (SBIC) information criteria will be consulted while post-estimation tests will be performed to check the residuals' properties. It needs to be stressed that specifying a VAR with the appropriate lag length is extremely important given that it is needed to have "Gaussian" error terms (meaning that they do not suffer from autocorrelation or heteroskedasticity and follow a normal distribution) (Asteriou and Hall, 2011). Regarding the deterministic components that should be included in the test equation (trend and intercept in the VAR or the cointegration relationship), the Pantula principle will be followed in order to avoid making a mistake in the cointegration test due to misspecification of the test equation.

Finally, as mentioned above, the Johansen test will also be performed after the inclusion of structural breaks (Johansen et al. 2000). In particular, the VEC model with breaks in 1914 and 1950 is estimated on Eviews following the methodology and code (for critical values) presented by Giles (2011). Additionally, it needs to be noted that since we allow for a break in both the intercept and the linear trend, only the model that includes a linear trend in the cointegration equation is estimated (model 4)[9].

After it has been decided whether a cointegration relationship exists, the VEC model will be estimated while the deterministic components included will be determined by the post- estimation tests of the VEC model's residuals. The estimated VEC model will thus include both the short-run as well as the long-run information that describe the relationship between energy consumption and economic activity. In its general and simplest form (without deterministic components) the VEC model will be

$$\Delta Y_t = \alpha_0 + \sum_{i=1}^{m} \alpha_{1i}\Delta Y_{t-1} + \sum_{i=1}^{m} \alpha_{2i}\,\Delta E_{t-i} - \theta_1(Y_{t-1} - \beta E_{t-1}) + \varepsilon_t \qquad (5)$$

$$\Delta E_t = \alpha_0 + \sum_{j=1}^{m} \alpha_{1j}\Delta E_{t-1} + \sum_{j=1}^{m} \alpha_{2j}\,\Delta Y_{t-j} - \theta_2(E_{t-1} - \beta Y_{t-1}) + v_t \qquad (6)$$

Where α_{ij} and are parameters to be estimated, *m* is the number of lags included while θ is the adjustment coefficient of the cointegration relationship. In other words it measures the speed of adjustment to the cointegration relationship while its statistical significance designates the long-run Granger causality between energy consumption and real GDP. As regards the *β* coefficient estimates, these designate the long-run relationship between the two variables.

[9] Detailed steps of the Johansen test with breaks can be found in Prof. David Giles blog: http://davegiles.blogspot.se/2011/05/cointegrated-at-hips.html

5. Results

5.1. Unit root test

In Tables A1- A3 in the Appendix the ADF, PP unit root and KPSS stationarity test results are presented for all eight countries and for the three distinct periods that are examined here. Before moving to the detailed presentation of the test results, it needs to be mentioned that the specifications which are reported with the relevant deterministic components (trend and intercept) and lag structures are the ones which fulfil the residuals' post-estimations tests. In other words, for all the tests which have been performed, autocorrelation in the residual terms has been corrected accordingly.

Beginning from Table A1 in the Appendix, that reports the tests' results for the whole period where data is available in each country, it can be seen that in most cases both energy consumption as well as real GDP series are I(1). Although, it needs to be noted that in the cases of England and Germany, there seem to be conflicting results among the three tests for the energy and GDP series respectively. Concerning England's energy consumption series, at a 5% significance level the unit root hypothesis of both the ADF and PP test is rejected implying a levels stationary process. On the contrary though, according to the KPSS test the stationarity null hypothesis is easily rejected. Given the low power of the ADF and PP tests and the fact that in most studies macroeconomic variables such as energy and GDP are found to be non-stationary it is concluded that England's energy series is also I(1). Regarding the case of Germany's logarithm of real GDP series, according to the ADF test it is suggested that the series is trend stationary. However, when cross-checking with the results of the other two tests, it is found that the series contain a unit root. It is generally argued that the PP test performs relatively better in bigger samples and for this reason it is decided to ignore the result of the ADF and conclude that the GDP series is I(1). Consequently, when examining the whole period of each country and not including any structural breaks all series are found to be I(1).

Regarding the period before 1970, the results in Table A2 in the Appendix suggest that the energy and GDP series of all countries are I(1). In fact there is a full consensus among the three different tests since in all cases the unit root/stationarity null hypothesis is rejected for the logarithmic series in levels. The same does not hold though for the series in the period from 1970 until 2009 (see Table A3 in the Appendix). Although again for the majority of the countries the "traditional" tests unanimously suggest that the series are I(1), the same does not apply for the real GDP series of Italy and Spain. In particular, for Italy the PP test suggests stationarity. However, it is decided to neglect this finding and conclude that the series contain a unit root (i.e. it is I (1)), since as mentioned earlier the test is suggested to perform better in bigger samples. Thus, in this case that the sample has decreased to 40 observations and given the low power of the test, it is considered better to trust the results of the ADF and KPSS tests. Concerning the case of Spain, the test results on the level series suggest stationarity according to the ADF test while the PP and KPSS show that there is a unit root. More importantly, the first differences of the series contain a unit root according to the ADF and PP tests. In this "peculiar" case it was decided to also conduct a unit root test with structural breaks for this period in order to be sure about the exact properties of the GDP series. It is concluded that the series are I(2) since when also cross-checking with the results of the Zivot- Andrews and Lee and Strazicich unit root tests with structural breaks for this period also a second order of integration is suggested[10].

Finally, concerning the unit root tests with structural breaks, the results of the Zivot-Andrews and Lee and Strazicich test are presented in Tables A4 and A5 in the Appendix. As mentioned earlier in the methodology part, the tests are applied only in the whole period for which data is available in each country. Overall from the tests it can be concluded that all the series are I(1) since the null hypothesis of unit root or unit root with structural breaks is not rejected for the logarithmic levels. The only exceptions are the cases of real GDP series for England and the Netherlands where there are conflicting results among the two tests when testing on levels. In fact according to the Zivot- Andrews test, both series is suggested to be stationary with structural breaks. However, as mentioned earlier the Zivot- Andrews test could is some cases be biased against rejection of the null hypothesis of unit root since it does not assume a break under its null hypothesis. For this reason and given that the traditional tests (ADF, PP and KPSS) also suggest the presence of unit root, the results of Lee and Strazicich are accepted i.e. both series are also I(1).

Regarding the timing of the structural breaks, although in some cases there are some similarities among the two tests, generally there is no consensus. More importantly, almost none of the two tests and especially the Lee and Strazicich, which allows for two breaks, specify a break in the energy consumption series within the decade of the 1970s as one would expect. On the contrary, a significant number of breaks have been specified in the preceding decade i.e. in the 1960. The only strong exception could be the Netherlands and maybe France and Italy where there is noticed a break associated with the oil price shocks or more importantly the third Industrial Revolution (see Table A5 in Appendix).

5.2. Granger causality

As it stems from the unit root tests presented above, for almost all the countries it was found that the series are I(1) (with and without structural breaks) both when examining the whole period but also when testing for the two different sub-periods. The only exception is the case of the Spanish real GDP series which was found to be I(2) in the period 1970-2009. For this reason, when performing the Granger causality test with the Toda and Yamamoto procedure for all periods, two extra lags of both variables were included in the specified VAR as exogenous variables. In the case of Spain for the period 1970-2009 two more lags were included as exogenous in the VAR due to the higher order of integration of the real GDP series. Additionally, it needs to be mentioned that in some cases the lag length specified by the Schwartz information criteria had to be increased in order to correct for autocorrelated residuals.

The results of the Granger causality test for the different periods are presented in Table 2. It is noted that these results do not include a structural break in the VAR specification. When examining the Granger causal relationship between energy consumption and real GDP in the whole period of each country, the results in Table 2 suggest a quite divergent pattern. However, for all the countries there is found a statistically significant causal relationship between the two variables. In fact, for France, Germany, Italy and Spain, the null hypothesis that energy consumption does not Granger

[10] After separately conducting both Zivot- Andrews (ZA) and Lee and Strazicich (LS) unit root tests in the period 1970-2009 for Spain, both tests suggest that the first differenced series of real GDP have a unit root at a 5% significance level (including breaks in intercept and trend). The ZA t-statistic is -3.09, significantly smaller in absolute value than the t-critical -5.08. The LS t-statistic is -3.122 with the t-critical values varying from -5.59 to - 5.74.

causes changes in real GDP can be rejected even at the 1% significance level. In other words the unidirectional Granger causality from energy to GDP provides a strong support to the “growth hypothesis” for these countries. Furthermore, regarding the rest of the countries and particularly the Netherlands and Sweden, an opposite channel of unidirectional Granger causality running from changes in real GDP to energy consumption is found to exist. This provides support to the “conservation” hypothesis and the idea that economic growth is the driving force in changes which occur in the energy consumption series. Finally, for England and Portugal bidirectional granger causality is found between the two variables providingng in this way support to the “feedback” hypothesis.

Concerning the question of whether the relationship between economic activity (specifically economic growth) and energy consumption changes after the 1970s, the results in Table 2 do support significant changes for most of the countries. Primarily though, it needs to be noted that during the period prior to 1970 (beginning year of each country until 1969) the Granger causal relationship between the two variables, for most of the countries remains the same with that found for the total period. The only exceptions are England (at the 5% and 1% significance levels) and Portugal. In fact, when testing at a 5% significance level for England, a unidirectional Granger causality describes the two variables providing a very strong support to the “conservation” hypothesis. Regarding Portugal, a neutral relationship seems to characterize energy and economic activity (fail to reject the null in both “causality” tests).

Table 2. Granger causality test results following Toda- Yamamoto procedure, no structural breaks

Variables	Periods		
	Total, in parenthesis	Beg.- 1969	1970-2009
England	**(1800- 2009)**		
GDP → Energy	0.00***	0.00***	0.00***
Energy → GDP	0.03**	0.09**	0.63
France	**(1820- 2009)**		
GDP → Energy	0.15	0.46	0.05**
Energy → GDP	0.00***	0.00***	0.53
Germany	**(1850- 2009)**		
GDP → Energy	0.44	0.56	0.87
Energy → GDP	0.00***	0.00***	0.60
Italy	**(1861- 2009)**		
GDP → Energy	0.28	0.26	0.12
Energy → GDP	0.00***	0.00***	0.48
Netherlands	**(1800- 2009)**		
GDP → Energy	0.00***	0.00***	0.75
Energy → GDP	0.51	0.53	0.15
Portugal	**(1850- 2009)**		
GDP → Energy	0.00***	0.62	0.05**
Energy → GDP	0.00***	0.82	0.36
Spain	**(1850- 2009)**		
GDP → Energy	0.36	0.68	0.52
Energy → GDP	0.00***	0.02**	0.40
Sweden	**(1800- 2009)**		
GDP → Energy	0.02**	0.03**	0.15
Energy → GDP	0.81	0.55	1.00

Note: The table reports the p- values of the Wald test; ***p<0.01, **p<0.05, *p<0.1. The arrows denote the direction of Granger causality between the two variables.

Overall, it can be seen that after the 1970s for almost all countries a neutral relationship between the two variables emerges. In particular, for Germany, Italy and Spain the unidirectional Granger causality from energy consumption to GDP stops to exist and the relationship between the two variables becomes neutral. Accordingly, for Sweden and the Netherlands the opposite unidirectional Granger causality ceases to hold and again economic activity and energy consumption seems to be better described by a decoupled relationship between the two. The only exceptions are England, France and Portugal. For England the unidirectional Granger causality from GDP to energy consumption continues to hold designating that the "conservation hypothesis" is supported for the country even until the recent years. On the contrary, for France the unidirectional Granger causality between the two variables changes direction and after the 1970s since economic activity seem to affect the energy consumption patterns of the country and not the other way around. As for the case of Portugal, after the 1970s a unidirectional Granger causality from GDP to energy consumption characterizes the country.

Table 3. Granger causality test results following Toda- Yamamoto procedure, structural breaks in 1914 and 1950

Variables	Periods		
	Total, in parenthesis	Beg.- 1969	1970-2009
England	**(1800- 2009)**		
GDP → Energy	0.00***	0.00***	0.01**
Energy → GDP	0.03**	0.02**	0.85
France	**(1820- 2009)**		
GDP → Energy	0.13	0.18	0.13
Energy → GDP	0.00***	0.00***	0.44
Germany	**(1850- 2009)**		
GDP → Energy	0.00***	0.64	0.65
Energy → GDP	0.41	0.00***	0.99
Italy	**(1861- 2009)**		
GDP → Energy	0.17	0.21	0.35
Energy → GDP	0.00***	0.00***	0.96
Netherlands	**(1800- 2009)**		
GDP → Energy	0.01**	0.01**	1.00
Energy → GDP	0.33	0.55	0.20
Portugal	**(1850- 2009)**		
GDP → Energy	0.92	0.77	0.13
Energy → GDP	0.01**	0.94	0.01**
Spain	**(1850- 2009)**		
GDP → Energy	0.73	0.54	0.76
Energy → GDP	0.03**	0.05**	0.24
Sweden	**(1800- 2009)**		
GDP → Energy	0.01**	0.01**	0.11
Energy → GDP	0.62	0.91	0.96

Note: The table reports the p- values of the Wald test; ***p<0.01, **p<0.05, *p<0.1. The arrows denote the direction of Granger causality between the two variables.

Accordingly, in Table 3, the results of the Granger causality test are presented after including structural breaks in the year of the First World War and the beginning of the "Golden Age" in Europe (1914 and 1950 respectively). For the majority of the countries, the inclusion of structural breaks does no change the conclusions regarding the direction of causality for all the periods ensuring the robustness of the results previously found. The only strong exceptions are Portugal and Germany for their total periods (1850-2009) for which the causal relationship changes with the inclusion of structural breaks. More specifically, for both Germany and Portugal the “conservation hypothesis” is now supported when examining the whole period with structural breaks. Finally, regarding the two sub-periods, the results remain the same for all countries for the period prior to 1969. As regards the period following the third Industrial Revolution, the results with structural breaks again remain the same for most countries suggesting that the relationship between economic activity and energy consumption becomes relatively neutral. In fact, the “neutrality hypothesis” is now backed-up even in the case of France.

Concluding, it could be argued that the direction of Granger causality for the whole period varies among the different countries significantly with both unidirectional as well as bidirectional relationships being present. However, the presented evidence in both Tables 2 and 3 provide strong support to the hypothesis that after the 1970s the role of energy in economic activity changes and in fact somewhat declines. In fact when not including any structural breaks, for five out of eight European countries no Granger causality is found between energy consumption and real GDP. Even in the three cases of England, France and Portugal that a statistically significant “causal” relationship is found, this runs only from real GDP to energy consumption supporting the “conservation hypothesis”. Accordingly, after the inclusion of two break points the relationship between energy consumption and real GDP becomes neutral even for the case of France strengthening further the hypothesis. The only ambiguous case is that of Portugal since the inclusion of structural breaks yields different results both for the whole period but more importantly the one after 1970. The strong coupled relationship between the two variables that was noticed after 1970 (see Table 1 and Figures 1 and 2) is also verify by the findings of the Toda-Yamamoto procedure.

5.3. Cointegration analysis

As mentioned earlier, another way to test the linkage between energy consumption and real GDP is to examine whether the two variables are cointegrated or not. In this way the long-run relationship that could potentially exist between the two variables can be examined and more importantly be estimated with the estimation of a VEC model afterwards. In order to test whether the two series are cointegrated the Johansen test for cointegration is employed.

After deciding the number of lags to be included in the tested VEC model using the Schwartz information criteria and conducting residual’s post estimation checks on a levels VAR, the results of the Johansen test without structural breaks are presented in Table 4. The test was conducted on the whole period of each country for which data is available. At the 5% significance level and following Pantula principle only for the cases of Germany and Portugal the null hypothesis of at most one cointegration relationship is not rejected providing a very strong support to the previous findings of Granger causality for the corresponding time period in these countries. Even though for the rest of the countries zero cointegration relationships are suggested according to Pantula principle at the 5% level, we can still be more lenient with the confidence intervals that are used and as mentioned in the methodology part test at the 10% level. In this respect, when testing at 10% it is found that a cointegration relationship exists for all countries except for Italy and the Netherlands. Although for Italy the critical value with Model 4 is very close to becoming significant (trace statistic= 22.72 and critical value= 23.34) a finding that increases the probability of a cointegration relationship to actually exist.

Table 4. Johansen cointegration test for the whole period of each country, no structural breaks

Models	Max Rank	Trace statistics								Crit. values	
		England	France	Germany	Italy	Netherlands	Portugal	Spain	Sweden	5%	10%
2	None	**56.31**	**27.96**	**25.53**	**25.55**	**28.28**	**35.97**	**29.70**	**73.39**	20.26	17.98
	At most 1	**15.26**	6.86	7.31	5.67	5.55	2.05	**11.67**	6.20	9.16	7.56
3	None	**20.15**	**14.58**	**16.86**	6.26	7.46	**27.20**	**16.47**	**14.51**	15.49	13.43
	At most 1	0.92	0.16	0.29	0.34	1.37	0.17	1.92	1.85	3.84	2.71
4	None	**24.08**	**24.96**	**26.77**	22.72	16.77	**37.98**	**24.12**	**27.27**	25.87	23.34
	At most 1	4.53	9.46	10.19	3.82	5.86	6.39	6.45	10.59	12.52	10.67

Note: Values significant at the 10% significant level are in bold
Model 2 includes no deterministic trends or intercept in VAR but an intercept in the CE (cointegrating equation)
Model 3 includes intercept in VAR and CE but no trends in VAR or CE
Model 4 includes intercept in VAR and intercept and trend in the CE

After having identified a cointegration relationship following Pantula principle for England, France, Germany, Portugal, Spain and Sweden a VEC model is estimated in order to define the direction of Granger causality and more importantly estimate the long-run relationship that characterizes the two variables in the whole period. It needs to be mentioned that in the estimated VEC the included deterministic components are not necessarily the ones suggested by Pantula principle i.e. the one at which we fail to reject for the first time the H_0. On the contrary, after a process of trial and error performing post-estimation checks on the residuals, an intercept and trend has been included in the cointegrating equation and an intercept in the VAR (Model 4) for four out of six countries. The exceptions are England and Germany, for which no trend has been included (Model 3) since this specification did not result in problems with the residuals.

The estimated parameters of the VEC model are presented in Table 5. For most cases the direction of causality found by the Toda and Yamamoto procedure is verified from the results in Table 5. In particular, for England and Portugal again bidirectional "causality" is suggested between energy consumption and real GDP given that the estimated adjustment coefficients of both equations (0.002 and -0.005 for England and -0.215 and -0.013 for Portugal) are found to be significant at 10%. Thus, both variables in England and Portugal are significantly adjusting to the cointegration relationship suggesting that they are endogenous to the system. Accordingly, for the cases of France and Spain, the adjustment coefficients in the equation of energy consumption (lnE) are statistically insignificant providing support to the "growth hypothesis" for these countries. In particular, it is suggested that energy consumption is exogenous to the system not adjusting to the cointegration relationship. Consequently, whenever there is a shock to the equilibrium relationship between the two variables, it is real GDP that re-adjusts to restore the equilibrium. The values of the speed of adjustment (α= -0.015 for France and α= -0.09 for Spain) designate that the gap between energy consumption and real GDP will decrease by approximately 1.5% and 1% respectively in each country. As regards Sweden, the results in Table 5, also support the findings from Toda- Yamamoto given that the adjustment coefficient of GDP is insignificant suggesting a Granger causality that runs from GDP to energy consumption. On the contrary though, conflicting results between the Toda-

Yamamoto without breaks (see Table 2) and the VEC model are found for Germany since according to the estimations a unidirectional Granger causality from GDP to energy consumption is found. However, this finding is in accordance with the direction of causality that stems after the inclusion of structural breaks (see Table 3).

Regarding the estimation of the long-run coefficients (β), these are also presented in Table 5. It is noted that in cases where a variable was found to be endogenous to the system, the normalization has been done on this variable while in the case of England and Portugal where both variables in suggested to be endogenous, energy consumption is treated as the dependent variable[11]. Primarily, it can be seen that all the long-run coefficients are statistically significant at the 5% significance level and have the expected sign. Regarding the effect of energy consumption on real GDP, the estimates of France and Spain are -3.16 and -1.21 respectively. This implies that a 1% increase in energy consumption, in the long-run is associated with an approximately 3.2% and 1.2% increase[12] in real GDP in these countries. This can be regarded as a relatively strong effect designating the big importance that energy played historically in these economies. Accordingly, the effect from a change in real GDP to energy consumption is reflected on the estimated long-run coefficients of England, Germany, Portugal and Sweden. The long-run effects vary from around 0.2% to 3.8%. The biggest effect from a 1% change in real GDP on energy consumption is noticed in England (3.8%) while the smallest corresponds to Germany (0.2%).

Table 5. Parameter estimates of VEC model for the whole period in each country, no structural breaks

Equation	Adj. Coef. (α)	Long-run coef. (β)	Adj. Coef. (α)	Long-run coef. (β)	Adj. Coef. (α)	Long-run coef. (β)	Adj. Coef. (α)	Long-run coef. (β)	Adj. Coef. (α)	Long-run coef. (β)	Adj. Coef. (α)	Long-run coef. (β)
	England		France		Germany		Portugal		Spain		Sweden	
lnGDP	0.002* (0.001)	-3.76*** (0.711)	-0.015*** (0.004)	1.00	0.011 (0.01)	-0.15** (0.174)	-0.215*** (0.043)	-0.64*** (0.049)	-0.092** (0.035)	1.00	-0.019 (0.035)	-1.4*** (0.136)
lnE	-0.005*** (0.001)	1.00	0.004 (0.005)	-3.16* (1.965)	-0.022** (0.007)	1.00	-0.013*** (0.029)	1.00	0.044 (0.028)	-1.21*** (0.087)	-0.068*** (0.021)	1.00

Note: Standard errors in parenthesis, *** p<0.01, ** p<0.05, * p<0.1

Concerning the existence of cointegration after the inclusion of structural breaks, the results of the Johansen test are presented in Table 6 below. Surprisingly though, when including structural breaks in the series in the years of 1914 and 1950, no cointegration relationship between energy consumption and economic growth is suggested. In fact for none of the countries the null hypothesis of zero cointegration relationship can be rejected neither at the 5% nor at the 10% significance level. It is only in the case of Germany that the trace statistic is relatively close to the 10% critical value and given the low power of the test could suggest that there might be a cointegration relationship but still no clear answer can emerge. Given the outcome and in order to be sure regarding the appropriate specification of the structural breaks, other key dates were also used as potential break dates that are expected to apply in most of the countries under study. In particular, in addition to the 1914 and 1950 break years, combinations with the years 1900, 1916 and 1973 well also applied.

[11] Even though the normalization for England and Portugal has been done on energy consumption, the relationship can easily be reversed (normalize on real GDP) simply by: $\beta_{gdp} = 1/\beta_{energy}$

[12] There is a change in the sign of the coefficient from minus to plus due to the formulation of cointegration equation. See equations 5 and 6 above.

However, even in these cases no cointegration relationship was suggested for none of the countries under study. Consequently, we do not proceed further in estimating the VEC models.

At this point it is necessary to stress that the fact that no cointegration is found when including structural breaks, although contradicts the previous findings for the total period and should raise cautiousness, it does not necessarily cancels out these results. Given that the Toda-Yamamoto procedure with and without structural breaks suggested some “causality” (unidirectional or bidirectional) between energy consumption and real GDP for all countries and furthermore the fact that the Johansen test without structural breaks suggests a cointegration for almost all countries provides strong evidence of the relationship between the variables. The contradicting results in Table 6 could be related to the low power of the test, but more probably to the fact that the breaks are exogenously determine and consequently may bias the outcome.

Table 6. Johansen cointegration test for the whole period of each country, with structural breaks in 1914 and 1950

Countries	Max rank	Trace statistic	Critical values	
			5%	10%
England	None	29.1	45.8	42.5
	At most 1	0.1	23.7	21.1
France	None	24.8	46.7	43.3
	At most 1	10.5	24.2	21.6
Germany	None	42.1	48.1	44.7
	At most 1	18.1	24.8	22.3
Italy	None	29.9	48.3	44.9
	At most 1	7.3	24.9	22.4
Netherlands	None	38.3	45.8	42.5
	At most 1	9.1	23.7	21.1
Portugal	None	29.2	48.1	44.7
	At most 1	6.4	24.8	22.3
Spain	None	20.8	48.1	44.7
	At most 1	3.5	24.8	22.3
Sweden	None	30.7	45.8	42.5
	At most 1	8.3	23.7	21.1

Note: The models that are estimated include intercept in the VAR and intercept and linear trend in the CE (Johansen’s Hl(r) model). The critical values are estimated based on the location of the break points; $V1=T_{B1}/T$ and $V2=T_{B2}/T$ (T= sample size)

6. Conclusions

The current study aimed to investigate the relationship between energy consumption and economic growth for eight developed European economies. More specifically, the "causal" relationship between energy consumption and real GDP series has been examined using the Granger causality and cointegration analysis in a dataset that overall spanned within a period of 210 years. The main purpose has been to define the long-run relationship between the two variables but also examine whether the relationship changes after the 1970s with the introduction of the third Industrial Revolution. The findings extend the already existing literature in the field that mainly employs smaller datasets while at the same time stresses the importance regarding the effect of energy conservation policies on these countries' growth potentials.

From a first preliminary analysis it was seen that energy consumption and economic growth have been characterized by a relatively coupled relationship in all countries before the 1970s. More specifically, there have been distinguished different sub periods which are characterized by similar growth patterns between energy consumption and real GDP while there are noticed break points in the years close to the First Industrial Revolution but also the First and Second Worlds Wars that unanimously affected the growth rates of both variables. However, after the 1970s, a change in the relationship is noticed for almost all countries with a decoupling between energy consumption and real GDP. The only exceptions are probably Spain but more clearly Portugal mainly due to their relatively later industrialization process.

Regarding the results of the econometric analysis, primarily from the unit root tests that were performed it was concluded that both variables in all countries are I(1) in both the whole period but also the two sub-periods before and after 1970. The only exception is Spain during the period 1970-2009 since the real GDP series was found to be I(2). Consequently, this allowed us to perform the Johansen cointegration test with and without structural breaks for the total period but also the Toda-Yamamoto procedure accordingly.

Regarding the findings on the Granger causality it is considered critical to discuss the obtained results under the light of the methodology that has been followed. Primarily, it needs to be stressed that not all of our findings are verified by the cointegration analysis. When not including structural breaks, the Johansen cointegration test suggested no cointegration in the cases of Italy and the Netherlands. More importantly though, the inclusion of structural breaks in the Johansen test suggests no cointegration for all countries between the two variables and consequently contradicts the findings of the Toda-Yamamoto procedure where causality is found in all countries. Nevertheless, given the low power of the test, the fact that cointegration is present when not including breaks for six countries, and more importantly the fact that the break points were exogenously determined, it is believed that a cointegration relationship actually exists. In this respect the results of the Johansen test with structural breaks is not considered very reliable. Secondly, as mentioned earlier, in the study only two variables are analyzed and this somewhat limits the depth of the analysis. In fact more variables like energy prices, labor and capital would provide a bigger insight on the actual direct or indirect causality channels that intervene in the relationship between energy consumption and real GDP providing more detailed information to policy makers. Yet still, the obtained results provide a more generalized picture to policy makers and give an adequate preliminary idea of the relationship between the two variables both in the total period of each country but also after the 1970s.

As regards the Granger causality results, following the Toda-Yamamoto procedure it has been found that the Granger causal relationship between energy consumption and real GDP follows a rather divergent pattern among the different countries in Europe. For the majority a unidirectional causal relationship has been suggested for the total period in each country with the only exception of England where bidirectional causality is found. After examining the results with and without structural breaks, the direction of causality is found to run from energy to GDP for France, Italy and Spain while the other way round in the cases of the Netherlands and Sweden providing support to the "growth" and "conservation" hypothesis respectively. Regarding Portugal and Germany, the findings for the whole period are arbitrary since the inclusion of structural breaks alters the results in these countries and thus no clear cut conclusions can be drawn. Nevertheless, what can still be said with a great degree of certainty is that the relationship between energy consumption and real GDP is not neutral in these countries. Concerning the relevance of the results with those of previous studies, it is argued that in general contradicting results are obtained proving that the period or sample size are crucial in determining the outcome. It is suggested that since this study examined data available for a bigger time period, the results obtained here reflect closer the true long-run relationship between energy consumption and economic activity for England, France, Italy, Netherlands, Spain and Sweden. Again for Germany and Portugal no clear pattern emerges.

Additionally, the cointegration analysis has allowed us to estimate this long-run relationship for six countries finding significant estimates for them. The long run estimations designate that energy conservation policies could actually be a threat only for the growth prospects of countries like France, and Spain, given that a one percent decrease in energy consumption would be associated with a 3.2% and 1.2% decrease in real GDP respectively. On the contrary, in the case of Sweden the long-run coefficient designated that a unit percent increase in real GDP is associated with a 1.4% increase in energy consumption stressing the need and usefulness of energy conservation policies in the country. For England, the bidirectional causality between energy consumption and real GDP is characterized by a long-run relationship of around 3.8% and 1/3.8% respectively.

However, there is strong evidence that the relationship between the two variables changes after the 1970s for almost all countries in Europe and this change cannot simply be attributed to the oil crisis that occurred in this decade. The relatively more permanent character that it has designates that other factors could be hidden behind, namely the third Industrial Revolution and the rising importance of information and communication technologies as drivers of economic growth and energy efficiency improvements.

Overall, in contrast to what has been found for the total period and that before the 1970s, from the obtained results it can be argued that there is no clear pattern that energy and more importantly today's energy conservation policies are a limiting factor to economic growth for almost all of the countries examined here. In fact, energy efficiency improvements mainly driven and developed during the ICT revolution seem to have set the basis for a new, hopefully more sustainable growth pattern in most European countries. The support of the "neutrality hypothesis" in Germany, Italy, Netherland, Spain and Sweden after 1970 is an encouraging sign towards this direction. At the same time, the "conservation hypothesis" which is supported in the case of England and potentially in France too designates that economic activity should actually be accompanied by policies that will encourage the decrease of energy consumption and that will mainly foster increases of energy efficiency.

The only arbitrary case is that of Portugal where a coupled relationship between energy consumption and economic growth exists after the 1970s and the causal relationship could actually run from energy to GDP. This could be due to the relatively later industrialization of the country that has not allowed it yet to fully grasp the “merits” of technological progress introduced by the ICT revolution and increase its energy efficiency. It partly implies that the country is probably not technologically ready yet to adopt energy conservation policies without at the same time putting in danger its growth potentials.

As a concluding remark it should be noted that the results and evidence presented in this study, although subject to the limitations imposed by the econometric methods that are used and the incorporation of only two variables, they still provide an encouraging message to the European Union’s policies towards a more environmentally sustainable economic growth. Nevertheless, at the same time they draw the attention to cases like Portugal signaling that one size definitely does not fit and some economies may still need time to adapt into this new growth pattern.

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Appendix A

Table A1. Unit root test for the corresponding total period of each country

Variables	Specification	ADF test		Phillips- Perron test		KPSS test	
		Z(t)	5% Crit. Value	Z(t)	5% Crit. Value	Test stat.	5% Crit. Value
England							
lnGDP	Intercept & Trend	-2.096 (4)	-3.436	-2.773	-3.435	**1.64**	**0.146**
lnE	Intercept	**-2.955 (8)**	**-2.883**	**-3.748**	**-2.883**	**19**	**0.463**
ΔlnGDP	Intercept	**-9.349 (3)**	**-2.883**	**-13.236**	**-2.883**	0.05	0.463
ΔlnE	Intercept & Trend	**-4.162 (7)**	**-3.437**	**-23.091**	**-3.436**	0.028	0.146
France							
lnGDP	Intercept	0.696 (5)	-2.884	0.527	-2.884	**17.5**	**0.463**
lnE	Intercept & Trend	-3.120 (0)	-3.436	-3.266	-3.438	**0.574**	**0.146**
ΔlnGDP	Intercept	**-6.733 (4)**	**-2.884**	**-11.839**	**-2.884**	0.225	0.463
ΔlnE	Intercept	**-6.993 (2)**	**-2.884**	**-12.475**	**-2.884**	0.035	0.463
Germany							
lnGDP	Intercept & Trend	**-3.724 (1)**	**-3.442**	-3.151	-3.442	**1.05**	**0.146**
lnE	Intercept	-2.458 (0)	-2.886	-2.565	-2.886	**14.3**	**0.463**
ΔlnGDP	Intercept	**-8.986 (1)**	**-2.886**	**-9.198**	**-2.886**	0.03	0.463
ΔlnE	Intercept	**-12.114 (0)**	**-2.886**	**-12.107**	**-2.886**	0.36	0.463
Italy							
lnGDP	Intercept	0.608 (2)	-2.887	0.527	-2.887	**14.5**	**0.463**
lnE	Intercept	-0.135 (1)	-2.887	0.113	-2.887	**13.8**	**0.463**
ΔlnGDP	Intercept	**-9.134(1)**	**-2.887**	**-8.816**	**-2.887**	0.219	0.463
ΔlnE	Intercept	**-8.571(1)**	**-2.887**	**-9.055**	**-2.887**	0.23	0.463
Netherlands							
lnGDP	Intercept & Trend	-2.403 (0)	-3.435	-2.338	-3.435	**3.97**	**0.146**
lnE	Intercept & Trend	-2.866 (2)	-3.436	-2.976	-3.435	**2.72**	**0.146**
ΔlnGDP	Intercept	**-14.858 (0)**	**-2.883**	**-14.879**	**-2.883**	0.26	0.463
ΔlnE	Intercept	**-11.561 (1)**	**-2.883**	**-13.448**	**-2.883**	0.10	0.463
Portugal							
lnGDP	Intercept & Trend	-1.547 (1)	-3.442	-1.520	-3.442	**3.87**	**0.146**
lnE	Intercept	1.755 (3)	-2.886	2.545	-2.886	**14.7**	**0.463**
ΔlnGDP	Intercept	**-13.635 (0)**	**-2.886**	**-13.591**	**-2.886**	0.117	0.146
ΔlnE	Intercept	**-4.747 (2)**	**-2.886**	**-12.433**	**-2.886**	0.104	0.146
Spain							
lnGDP	Intercept	1.590 (1)	-2.886	1.839	-2.886	**14.8**	**0.463**
lnE	Intercept & Trend	-1.858 (2)	-2.886	-1.686	-3.442	**3.57**	**0.146**
ΔlnGDP	Intercept	**-9.831 (0)**	**-2.886**	**-9.842**	**-2.886**	0.44	0.146
ΔlnE	Intercept	**-5.476 (1)**	**-2.886**	**-11.951**	**-2.886**	0.131	0.146
Sweden							
lnGDP	Intercept & Trend	-2.559 (0)	-3.435	-2.580	-3.435	**4.34**	**-0.146**
lnE	Intercept & Trend	-2.317 (1)	-3.436	-2.374	-3.435	**3.8**	**0.146**
ΔlnGDP	Intercept	**-14.084 (0)**	**-2.883**	**-14.080**	**-2.883**	0.131	0.146
ΔlnE	Intercept	**-18.115 (0)**	**-2.883**	**-18.01**	**-2.883**	0.208	0.463

Note: Values in parenthesis correspond to the number of lags included in the specification while values significant at the 5% significant level are in bold.

Table A2. Unit root test for the period from the beginning until 1970 for each country

Variables	Specification	ADF test		Phillips- Perron test		KPSS test	
		Z(t)	5% Crit. Value	Z(t)	5% Crit. Value	Test stat.	5% Crit. Value
England							
lnGDP	Intercept & Trend	-2.041 (4)	-3.441	-2.627	-3.441	**2.46**	**0.146**
lnE	Intercept	-2.807 (6)	-2.886	-2.560	-2.885	**15.9**	**0.463**
ΔlnGDP	Intercept	**-8.433 (3)**	**-2.886**	**-12.174**	**-2.886**	0.04	0.463
ΔlnE	Intercept & Trend	**-5.881 (5)**	**-3.442**	**-21.977**	**-3.441**	0.04	0.146
France							
lnGDP	Intercept & Trend	-2.517 (3)	-3.444	-1.850	-3.443	**0.708**	**0.146**
lnE	Intercept & Trend	-3.405 (3)	-3.444	-3.124	-3.444	**0.46**	**0.146**
ΔlnGDP	Intercept	**-5.526 (2)**	**-2.887**	**-10.525**	**-2.887**	0.198	0.463
ΔlnE	Intercept	**-6.188 (2)**	**-2.887**	**-10.956**	**-2.887**	0.047	0.146
Germany							
lnGDP	Intercept & Trend	-3.106 (2)	-3.448	-3.013	-3.448	**0.367**	**0.146**
lnE	Intercept	-1.627 (0)	-2.889	-1.658	-2.889	**10.6**	**0.463**
ΔlnGDP	Intercept	**-7.729 (1)**	**-2.889**	**-7.897**	**-2.889**	0.065	0.463
ΔlnE	Intercept	**-10.620 (0)**	**-2.889**	**-10.636**	**-2.889**	0.14	0.463
Italy							
lnGDP	Intercept	1.294 (2)	-2.890	1.250	-2.889	**10**	**0.463**
lnE	Intercept	1.656 (2)	-2.890	1.880	-2.890	**8.56**	**0.463**
ΔlnGDP	Intercept	**-7.837 (1)**	**-2.890**	**-7.451**	**-2.890**	0.309	0.463
ΔlnE	Intercept	**-7.483 (1)**	**-2.890**	**-7.597**	**-2.890**	0.393	0.463
Netherlands							
lnGDP	Intercept & Trend	-2.317 (0)	-3.441	-2.266	-3.441	**1.81**	**0.146**
lnE	Intercept & Trend	-2.866 (2)	-3.441	-3.130	-3.441	**1.01**	**0.146**
ΔlnGDP	Intercept	**-10.723 (1)**	**-2.886**	**-13.438**	**-2.885**	0.255	0.463
ΔlnE	Intercept	**-10.723 (1)**	**-2.886**	**-12.016**	**-2.886**	0.178	0.463
Portugal							
lnGDP	Intercept & Trend	0.877 (1)	-3.448	0.803	-3.447	**2.36**	**0.146**
lnE	Intercept	2.302 (1)	-2.889	2.272	-2.889	**11.6**	**0.463**
ΔlnGDP	Intercept	**-13.577 (0)**	**-2.889**	**-13.342**	**-2.889**	0.409	0.463
ΔlnE	Intercept	**-12.912 (0)**	**-2.889**	**-12.809**	**-2.889**	0.396	0.463
Spain							
lnGDP	Intercept	2.245 (0)	-2.889	2.079	-2.889	**10.8**	**0.463**
lnE	Intercept & Trend	1.680 (1)	-3.448	1.403	-3.448	**1.72**	**0.146**
ΔlnGDP	Intercept	**-8.829**	**-2.889**	**-8.802**	**-2.889**	0.141	0.463
ΔlnE	Intercept	**-5.695**	**-2.889**	**-11.812**	**-2.889**	0.393	0.463
Sweden							
lnGDP	Intercept & Trend	-0.581 (2)	-3.441	-0.460	-3.441	**3.41**	**0.146**
lnE	Intercept & Trend	-0.261 (4)	-3.441	-0.414	-3.441	**3.03**	**0.146**
ΔlnGDP	Intercept	**-12.941 (0)**	**-2.889**	**-12.942**	**-2.889**	0.18	0.463
ΔlnE	Intercept	**-16.618 (0)**	**-2.889**	**-16.505**	**-2.889**	0.265	0.463

Note: Values in parenthesis correspond to the number of lags included in the specification while values significant at the 5% significant level are in bold.

Table A3. Unit root test for the period 1970-2009 for each country

Variables	Specification	ADF test		Phillips- Perron test		KPSS test	
		Z(t)	5% Crit. Value	Z(t)	5% Crit. Value	Test stat.	5% Crit. Value
England							
lnGDP	Intercept & Trend	-3.257 (1)	-3.548	-2.228	-3.544	**0.38**	**0.146**
lnE	Intercept	-2.079 (0)	-2.961	-2.217	-2.961	**0.872**	**0.463**
ΔlnGDP	Intercept	**-3.925 (0)**	**-3.925**	**-3.834**	**-2.964**	0.086	0.463
ΔlnE	Intercept	**-5.810 (0)**	**-2.964**	**-5.798**	**-2.964**	0.105	0.463
France							
lnGDP	Intercept & Trend	-3.332 (0)	-3.544	-3.329	-3.544	**0.379**	**0.146**
lnE	Intercept	-2.301 (0)	-2.961	-2.307	-2.961	**2.23**	**0.463**
ΔlnGDP	Intercept	**-4.368 (0)**	**-2.964**	**-4.250**	**-2.964**	0.42	0.463
ΔlnE	Intercept	**-6.985 (0)**	**-2.964**	**-7.062**	**-2.964**	0.067	0.463
Germany							
lnGDP	Intercept & Trend	-3.273 (0)	-3.544	-3.233	-3.544	**0.521**	**0.146**
lnE	Intercept & Trend	-3.197 (0)	-3.544	-3.233	-3.544	**0.521**	**0.146**
ΔlnGDP	Intercept	**-6.425 (0)**	**-2.964**	**-6.425**	**-2.964**	0.201	0.463
ΔlnE	Intercept	**-5.856 (0)**	**-2.964**	**-5.837**	**-2.964**	0.226	0.463
Italy							
lnGDP	Intercept	-2.759 (0)	-2.961	**-3.040**	**-2.961**	**3.88**	**0.463**
lnE	Intercept	-1.726 (0)	-2.961	-1.734	-2.961	**3.81**	**0.463**
ΔlnGDP	Intercept	**-5.298 (0)**	**-2.964**	**-5.352**	**-2.964**	0.393	0.463
ΔlnE	Intercept	**-5.783 (0)**	**-2.964**	**-5.879**	**-2.964**	0.252	0.463
Netherlands							
lnGDP	Intercept & Trend	-2.635 (1)	-3.548	-2.078	-3.544	**0.475**	**0.146**
lnE	Intercept & Trend	-3.423 (0)	-3.544	-3.413	-3.544	**0.169**	**0.146**
ΔlnGDP	Intercept	**-3.754 (0)**	**-2.964**	**-3.726**	**-2.964**	0.112	0.463
ΔlnE	Intercept	**-6.274 (0)**	**-2.964**	**-6.364**	**-2.964**	0.09	0.463
Portugal							
lnGDP	Intercept	-1.167 (1)	-2.964	-2.377	-2.961	**3.96**	**0.463**
lnE	Intercept	-1.528)4)	-2.972	-1.891	-2.961	**3.99**	**0.463**
ΔlnGDP	Intercept	**-3.692 (0)**	**-2.964**	**-3.665**	**-2.964**	0.07	0.146
ΔlnE	Intercept	**-2.993 (3)**	**-2.972**	**-5.035**	**-2.964**	0.313	0.463
Spain							
lnGDP	Intercept & Trend	**-4.909 (1)**	**-3.548**	-3.195	-3.544	**0.182**	**0.146**
lnE	Intercept	-1.593 (1)	-2.964	-1.976	-2.961	**3.75**	**0.463**
ΔlnGDP	Intercept	-1.711 (0)	-2.964	-1.863	-2.964	0.344	0.463
ΔlnE	Intercept	**-3.420 (0)**	**-2.964**	**-3.512**	**-2.964**	0.410	0.463
Sweden							
lnGDP	Intercept & Trend	-2.871 (1)	-3.548	-1.977	-3.544	**0.395**	**0.146**
lnE	Intercept & Trend	-3.440 (0)	-3.544	-3.528	-3.544	**0.181**	**0.146**
ΔlnGDP	Intercept	**-4.590 (1)**	**-2.966**	**-3.704**	**-2.964**	0.112	0.463
ΔlnE	Intercept	**-7.251 (0)**	**-2.964**	**-7.424**	**-2.964**	0.036	0.463

Note: Values in parenthesis correspond to the number of lags included in the specification while values significant at the 5% significant level are in bold.

Table A4. Zivot- Andrews unit root test with one break for the whole period in each country

Variables in levels	Change in intercept and trend slope		Variables in differences	Change in intercept	
	t- stat.	Break		t- stat.	Break
England			**England**		
lnGDP	**-6.828 (0)**	1918	ΔlnGDP	**-13.412 (0)**	1921
lnE	-3.551 (1)	1880	ΔlnE	**-11.615 (3)**	1908
France			**France**		
lnGDP	-3.655 (0)	1949	ΔlnGDP	**-12.984 (0)**	1945
lnE	-3.810 (0)	1962	ΔlnE	**-13.181 (0)**	1945
Germany			**Germany**		
lnGDP	-4.893 (1)	1959	ΔlnGDP	**-9.551 (1)**	1949
lnE	-3.544 (0)	1914	ΔlnE	**-13.184 (0)**	1946
Italy			**Italy**		
lnGDP	-3.357 (2)	1957	ΔlnGDP	**-10.669 (1)**	1946
lnE	-4.478 (1)	1959	ΔlnE	**-10.629 (0)**	1946
Netherlands			**Netherlands**		
lnGDP	**-5.526 (0)**	1946	ΔlnGDP	**-15.642 (0)**	1946
lnE	-4.762 (0)	1962	ΔlnE	**- 12.183 (1)**	1946
Portugal			**Portugal**		
lnGDP	-3.416 (0)	1903	ΔlnGDP	**-15.233 (0)**	1919
lnE	-3.646 (0)	1914	ΔlnE	**-14.333 (0)**	1953
Spain			**Spain**		
lnGDP	-4.164 (1)	1936	ΔlnGDP	**-10.828 (0)**	1950
lnE	-2.924 (2)	1926	ΔlnE	**-6.474 (1)**	1977
Sweden			**Sweden**		
lnGDP	-3.033 (0)	1946	ΔlnGDP	**-15.081 (0)**	1971
lnE	-3.161 (1)	1960	ΔlnE	**-19.083 (0)**	1971

Note: Values in parenthesis correspond to the number of lags included in the specification while values significant at the 5% significant level are in bold. The critical value at the 5% significance level when including a break in both the intercept and the trend is -5.08. The critical value when allowing for a break only in the intercept is -4.8.

Table A5. Lee and Strazicich LM unit root test with two breaks for the whole period in each country

Variables in levels	Change in intercept and trend slope, "Break" model			Variables in differences	Change in intercept, "Crash" model		
	Test stat.	Break 1	Break 2		Test stat.	Break 1	Break 2
England				**England**			
lnGDP	-5.2918	1840	1918	ΔlnGDP	**-14.4668**	1918	1943
lnE	-5.3494	1842	1878	ΔlnE	**-18.9916**	1870	1931
France				**France**			
lnGDP	-5.4273	1940	1970	ΔlnGDP	**-11.7118**	1870	1941
lnE	-4.6029	1938	1970	ΔlnE	**-14.1656**	1927	1945
Germany				**Germany**			
lnGDP	-4.2568	1944	1960	ΔlnGDP	**-9.7851**	1867	1947
lnE	-4.6815	1912	1954	ΔlnE	**-12.8382**	1914	1947
Italy				**Italy**			
lnGDP	-4.5728	1943	1973	ΔlnGDP	**-12.352**	1944	1970
lnE	-5.68	1942	1968	ΔlnE	**-9.4923**	1948	1973
Netherlands				**Netherlands**			
lnGDP	-4.8314	1925	1946	ΔlnGDP	**-15.1836**	1917	1976
lnE	-4.81	1939	1970	ΔlnE	**-15.5381**	1944	1972
Portugal				**Portugal**			
lnGDP	-4.3912	1913	1963	ΔlnGDP	**-14.9379**	1948	1991
lnE	-4.0066	1915	1967	ΔlnE	**-131080**	1958	1990
Spain				**Spain**			
lnGDP	-3.7395	1947	1971	ΔlnGDP	**-10.6293**	1897	1950
lnE	-3.2959	1952	1969	ΔlnE	**-8.4688**	1945	1992
Sweden				**Sweden**			
lnGDP	-3.5823	1879	1963	ΔlnGDP	**-14.8057**	1906	1976
lnE	-4.817	1863	1963	ΔlnE	**-18.1716**	1923	1985

Note: Values significant at the 5% significance level are in bold. The specific critical values for the "Break" model depend on the location λ=TB/T of the break point. In general, they vary between the values of -5.74 and -5.59.