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For Peer Review

INDUSTRIAL ENERGY INTENSITIES IN THE UK:

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Dear Professor Taylor,

I would like to thank you and the referees for the feedback we have received on our paper. We were very encouraged by the fact that referees found our work interesting and we thank them very much for spending their valuable time reading our article. We genuinely believe that we have accommodated all the points raised by you and the referees. Please find below the list of the specific comments and our responses to them. Our response is typed in red ink following the word "**Reply:**".

Best wishes,
The Authors

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1. The article contains several typing errors and they have to be corrected. **Reply**: The article was sent again for proof-reading

2. The article says that long-term differences are either stochastic or deterministic. Does this imply anything in regard to the form of Equation 1 on page 6. If it does, then how should the equation be. **Reply**: The regression in the article wanted to be a general representation of the differences among the series and the benchmark. We have now a more detailed equation for the case where differences are deterministic and another for the case of stochastic differences – see section 4.

3. On page 6, the author(s) wrote: "The nature of the differences among the series can be assessed by testing for the presence of unit roots ....". Does this statement talk about time series of different sectors or a time series for one sector. **Reply**: both – it depends on whether one uses univariate unit root tests or panel tests. This is hopefully clarified in the text.

4. All in all, more clarification has to be given for the term "Long Term Differences". Does this term stand for a difference between a time series observation and a benchmark or for a difference between several time series. This comment is mainly about pages 1 and 6. **Reply**: if there is a difference between a set of series and their benchmark, then it seems to us that there is a difference among the series themselves as the benchmark is

fixed. Apart from this, we clarified that differences are taken with respect to a benchmark by repeating the definition of the variable for the unit root analysis ($y_{it}^{d} = Y_{it} - Y_{bt}$) on page 6 (now page 11) and by defining more accurately long-term differences on page 1 (now page 2).

5. What are GVA and ONS on page 8. It is sufficient to give the full term for each one only on this page. **Reply**: The meaning of the acronyms has been added in the text

6. What does ISIC on Table 1 stand for? **Reply**: We now understand that ISIC is used only in the UK to indicate the NACE taxonomy. Table 1 has been edited

7. What is the equation of the time series that is being tested by ADF? It would be better to give this equation. **Reply**: This has been added to the text (see page 12).

8. The article can be recommended for publication after considering the questions and comments given above. **Reply**: We tried our best to accommodate the issues mentioned above.

1. The paper could be structured better. I would like to see a shorter introduction which says briefly what the paper is going to do and what the reader will learn from the paper. **Reply**: Section I has been shortened, i.e. cut to about half the original length. We added an introductory paragraph. As suggested by the referee we mention what the paper is going to do and the conclusions which can be drawn without going into details. Section **II** should be a discussion of why differences in energy intensities are stochastic or deterministic matters. Some of this is discussed on pp. 5-7, together with the methodology. The motivation deserves its own section and could be expanded a bit. **Reply**: Section II now contains only a discussion of the motivations of our study. This discussion has been built from the contents of the pages mentioned above by the referee, although it has been expanded. Section **III** should be a review of the existing literature (which is currently in the introduction). The literature review should end by pointing out the gaps and saying which of these gaps this paper addresses **Reply**: Section III has been added to the manuscript. As required by the referee, the literature review has been dropped from the introduction. It has been considerably expanded and now mentions the gaps this article aims to fill. Section **IV** should be the methodology. **Reply**: done. Section **V** should be the data description, Section **VI** the results of the univariate tests, Section

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VII the results of the panel tests. **Reply**: Section V, VI and VII have been structured in the way suggested by the referee. Section VIII discusses our findings while section IX presents the conclusions from our study. Section IX has been added to the paper while Section VIII has been built from the Conclusion sections of the previous draft- - although it has been considerably expanded.

A disjoint in the paper is that the univariate tests w/o structural breaks are followed by the panel tests w/o structural breaks followed by the univariate tests with structural breaks followed by the panel tests with structural breaks. It would make more sense to have the univariate tests w/o structural breaks followed by the univariate tests with structural breaks followed by the panel tests without and with structural breaks. There would not need to be much additional information to address this criticism. Instead, what is there could be presented more logically. **Reply**: The reason for organising the paper in this fashion was related to our intention to stress the effect of modelling breaks on the results. However, we have now re-organised the paper in the way suggested by the referee.

2. For the univariate tests reported in Table 2, what critical values (CVs) are being used? Given the small sample sizes (26 or 34 observations) the CVs should be simulated. While the Elliott, Rothenberg and Stock (1996) tests are supposed to have superior small sample properties, I think the CVs given in their article are based on N=50. Were these CVs used? **Reply**: Correct we used those CVs (ERS 1996 – Table 1), which are simulated with N =50, 100, 200 and infinite. We now discuss this issue in the text and we thank the referee to draw our attention to this. This is likely the cause explaining the rejection occurring in M^{GLS} tests. However, while the point raised by the referee is a fair point, we do not see much value in simulating CVs on the basis of the number of observations in the sample. Considering the results from the tests (H_0 cannot be rejected except in a couple of instances) and that simulating the CV would imply higher CVs (because our sample is lower than those used in the simulations from which we take the CV), simulating the CVs would further decrease the number of rejections in the table. As we overall conclude that series do have a unit root on the basis of our results in Table 2, simulating CVs is not likely to affect this conclusion. We argue this point of view in the paper. We think this is a decent compromise between methodological rigour (as we acknowledge the importance of this issue in the text) and practical constraints related to time available on a research project (especially considering that the insights from simulating CVs would be minimal). We would also like to point out that the meat of the paper is on the modelling of structural breaks rather than the tests presented in Table 2. It

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seems to us that in the literature it is customary to report the results from these tests by using tabulated rather than simulated CVs.

3. At the beginning of the section on panel testing, it would be useful to say which panel tests the authors intend to implement. This can be followed by a brief discussion of the pros and cons of each test that they intend to implement. In discussing the tests, it would be logical to start with the homogenous tests, proceed to the heterogeneous tests and finally the test allowing for cross-sectional dependence. **Reply**: We now mention upfront the tests we are going to implement. We discuss the limitations of panel tests in the order suggested above and for each criticism we mention which tests among those implemented in the paper are affected by the criticism.

4. Given the stated advantages of the LM tests with structural breaks over the ADF-type tests with structural breaks (as discussed on pp. 14-15), why do the ZA and LP tests at all? Why not just present the results of the LM tests with one and two breaks? **Reply**: We agree with the referee and the results from the ZA and LP tests have now been dropped. We also refer a number of articles presenting only results from the LM test, as suggested by the referee.

5. The sample size seems too small, at least to do the univariate two break tests. With the trimming region set equal to 0.15 (as usual) there is virtually no degrees of freedom. **Reply**: We are a bit puzzled by this remark. Trimming does not imply dropping observations from the sample but simply assuming that no breaks occurred in the first and last, say, 15% of observations. The regressions are run over the whole sample but the dummies to simulate the breaks are inserted only for the time span (0.15T, 0.85T) where T is the whole timespan. The rationale of having a sample of say 100 observations, throwing 15 observations away at each side and then using 70% of the observation to do the modelling is somewhat unclear. How would the results from this procedure differ from those using only a shorter sample (i.e. the central 70% of the longer sample) without any trimming? We acknowledge that same articles in the literature are a bit unclear on this. However ILT (2005: p413) (quoted in our paper) mentions that "the shift locations are determined through a grid search over the time interval [0.10T, 0.90T]". This suggests to us that the breaks cannot occur on the first and last 10% observations of the sample, as those locations are excluded from the grid search, but it does not suggest us that those observations are thrown away from the sample. Similarly, ZA (1992) run an empirical analysis using the test they propose. They use the database from Nelson and

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Plosser (1982). From Table 4 of NP (1982) we see that real GNP spans the period 1909-1970. However, ZA (1992) when applying their test reports a T of 62 – see Table 6. If they had discarded x% of the observations, the T of the sample would have been consequently reduced. This can be taken as evidence that trimming refers to the sample over which breaks are allowed to occur not to the sample used in the regression. We believe that our augment is correct. However, should our understanding be wrong, we can argue that our long sample goes from 1967 to 2007 and that we have dropped the first and last 10%, therefore making it equal to the 1970-2004 used in the estimation. The rationale of this is still unclear to us but then, should our understanding be wrong, we can say that our procedure conforms to common practice in the literature.

6. The selection of the model (model A or C [in the one break case] or AA or CC [in the two break case] should be discussed in the text and not relegated to the Table. **Reply**: This is now discussed in the text – see Section 6.

7. What CVs are used for the ZA and LP tests? I can't this discussed anywhere. You need to simulate the CVs. This should be done for N=26 and N=34 and the simulated CVs reported. **Reply**: Following advice from this referee - see point 4 above - the results from the ZA and LP tests have now been dropped.

8. In the univariate results, why is energy intensity in some sectors stationary and not in others? Is there anything about the nature of particular industries and their energy use that can be linked back to the finding of whether energy intensities are deterministic or stochastic? **Reply**: The reasons why in some cases long-term differences appeare to be stochastic is now discussed in Section VIII.

9. Problems with References Some references cited in the text are missing from the references – eg. Hlouskova & Wagner (2006); Narayan & Smyth (2005); Wagner (2005) Breitung & Pesaran (2005) listed in references as forthcoming Pesaran (2006) listed in references as forthcoming Mehara (2007) in text but listed as (2006) forthcoming in references Hooi & Smyth (2007) should be Lean & Smyth (2007) (Hooi is the given name) **Reply**: references have been revised and in some cases dropped. In the case of Breitung & Pesaran (2005), 2005 referred to the chapter, written originally in 2005, while forthcoming referred to the collection of essays comprising the chapter. This collection has been published only after we submitted our paper, i.e. at that time it was forthcoming. We thank the referee for mentioning our mistake related to Hooi and Smyth (2007). We

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are actually a bit puzzled by this author – Applied Economics report that paper as "**Authors:** Lean Hooi Hooi [ab]; Russell Smyth[a]" which makes us think that Lean is a first name. However, we follow the advice of the referee and Hooi and Smyth (2007) is now referred as Lean and Smyth (2007)

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INDUSTRIAL ENERGY INTENSITIES IN THE UK: IS THERE A DETERMINISTIC OR STOCHASTIC DIFFERENCE AMONG SECTORS?

Abstract

Energy intensities of industrial subsectors differ widely due to differences in the final product and ultimately in the production process. The aim of this paper is to assess whether these differences are stochastic or deterministic. The analysis is implemented for a number of British industrial subsectors over the 1970-2004 and 1978-2004 time periods. It turns out that the results of the tests are very influenced by whether one allows for the presence of structural breaks. Only when modelling structural breaks, one can conclude that the evidence in favour of the long-term differences being deterministic outbalances the evidence pointing to their nature being stochastic. This supports the adoption of policy instruments which are applied across productive sectors in a way which is not affected by the short-run evolution of the sectors.

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1 Introduction

Industrial energy consumption has been one of the main targets of policies aimed at increasing energy efficiency or reducing carbon emissions. The EU Emission Trading Scheme, for example, is focused exclusively on some of the most energy intensive industrial subsectors (see Annex I of the 2003/87 EC Directive). Other examples are provided by policy instruments, such as the Climate Change Levy and the Climate Change Agreement in the UK, the Swedish and German environmental tax reform, and the energy taxes and related energy efficiency agreements introduced in the Netherlands and Denmark (Speck et al 2006). Despite concerns related to industrial competitiveness, some other sources of CO_2 emissions have not been regulated as much as the industrial sector (OECD 2006).

Energy consumption, like the consumption of any productive factors, is determined by the final product and the used technology. It goes without saying that the energy intensity, i.e. the ratio between energy consumption and economic activity, of, say, the chemical sector will be different from that of, say, the construction sector. The existence of different energy intensities across industrial subsectors is simply a fact. This study assesses whether long-term differences among the energy intensities of the British industrial subsectors are deterministic or stochastic. For each industrial subsector we first determine the difference between its energy intensity and the intensity of the industrial sector as a whole, and then we assess the nature of these differences, which are called long-term differences, as they persist across time. From a time series point of view these differences can be either deterministic, i.e. can be approximated by an intercept and a time trend possibly subject to breaks, or they are stochastic, i.e. they are unpredictable but persistent. In fact, the properties of long-term differences are related to the properties of the innovation terms, i.e. the random shocks to the series. If these are transitory, long-term differences will be

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deterministic. If random shocks are persistent, they accumulate across time and long-term differences will be stochastic. After assessing the nature of the differences among energy intensities of the British industrial subsectors, this article discusses the policy implication of our analysis.

A number of contributions to the energy literature can be found in this study. First of all, as far as we know, no article in the literature has so far assessed the nature of the differences among energy intensities of industrial subsectors by adopting the approach discussed in this paper. By focusing on the properties of a time series relative to a benchmark, we apply a methodology relatively common in a number of economic fields which has been applied rarely to an energy dataset – see Lee et al (2008) and Robinson (2007). In addition, as far as the authors of this article are aware, the DF^{MAX}, the DF^{RMA}, the LM test with one and two breaks, and the CIPS test have never been applied in the energy literature. We also discuss a number of limitations of panel unit root tests. However, in this article we do not exhaustively implement panel tests, as modelling structural breaks seems a more promising avenue. From both univariate and panel tests, we can conclude that long-term differences among the energy intensities of industrial subsectors are deterministic if the testing procedure allows for breaks.

This paper is structured as follows. Section 2 describes the motivation of this study. Section 3 frames our contribution in the literature and surveys a number of studies which have taken an approach similar to ours. Section 4 introduces our methodology while Section 5 describes the dataset used in this study. Section 6 presents the results from univariate unit root tests with and without structural breaks. After stressing the limitations of panel testing procedures, Section 7 applies a number of tests so as to asses whether a panel approach confirms the results from the

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univariate tests described in the previous section. Finally, Section 8 discusses the findings from our study while Section 9 draws some conclusions.

2 Motivation of this study

Energy intensity is a ratio which has received considerable attention in the academic and policy making community. From a policy point of view, energy intensity is related to energy efficiency, i.e. the focus of a number of policies adopted in several countries (World Energy Council 2004) and a priority for the European Commission and Member States (DTI 2006). Energy efficiency is the ratio between energy services and energy consumption. As the former are difficult to measure, and in some cases even to define, energy intensity is normally used in policy-making and sets of indicators are regularly produced by a number of governments. These indicators can be used to help raise public awareness; complement other inputs to policy and program analyses; and increase the role of energy efficiency measure in the market (US DoE 2006). Energy intensity is also particularly important in the studies adopting the index decomposition approach - see Ang and Zhang (2000) for a review. In some of these studies energy intensity is the left hand side variable which is decomposed. When energy consumption or carbon emissions are decomposed, energy intensity is strictly related to one of the right hand side variables, i.e. the intensity effect.

This study has a number of aims and motivations. By using unit root tests, we assess the long-term differences among the energy intensities of industrial subsectors and draw conclusions on the frequency of the changes in these differences. In the trend-cycle decomposition of Beveridge and Nelson (1981), if a time series has no unit root, the trend reduces to a deterministic function of time while if it has a unit root, the direction of the trend changes at every point in time. Applying unit root tests

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enables us to assess whether changes in the differences occur either in every point in time or never at all. Applying unit root tests allowing for structural breaks enable us to assess whether changes occur in every point in time or at most occasionally, i.e. at the occurrence of the breaks (Perron 2006).

The nature of the long-term differences among the energy intensities of industrial subsectors affects policy-making with regard to the timing and frequency of policy interventions and with regard to the choice of policy instruments. Most of these policy implications are similar to those normally discussed in the studies assessing the stationarity of an economic time series – see for example Chen and Lee (2007) and Narayan and Smyth (2007) – although some implications are specific to the studies assessing the difference of a time series from a benchmark. From a policy point of view, given the downward trend in energy intensity in the industrial sector (see the Odyssee database and Figure 1 below), policy makers are likely to have a special interest in the time pattern of energy intensities of a number of sectors or equivalently in their long-term differences with a benchmark. This special interest could be motivated by the fact that some sectors are considered energy inefficient, compared to international benchmarks, or politically-sensitive.

If long-term differences among industrial sectors are stochastic, short-term random difference accumulated across time, as a certain component of the shocks to the series persists indefinitely. When policy makers have an interest in the series following a certain time pattern, they will need to intervene any time a random shock pushes the series in a direction opposite to that desired by policy makers. On the other hand, when long-term differences are deterministic, the series reverts to its deterministic components, as random shocks will naturally dissipate across time. In this case, policy makers do not need to intervene at any single minor departure of the series from the desired time pattern. In fact, if they want to affect the evolution of the

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series, policy makers will need to implement prolonged policy measures able to affect the deterministic components of the series. Only concerted and prolonged efforts will have an effect on long-term differences. Unfortunately, policies determined by the electoral cycle or any other short-term mechanism will have no lasting effect on the value of the long-term differences.

The nature of long-term differences is also important to assess the ability to forecast future values on the basis of past behaviour. In fact, the use of univariate time-series models for short-term forecasting is related to the persistency of shocks. If shocks do not persist indefinitely, a time series will return to its path and it will be possible to forecast future value based on its past behaviour. If a significant portion of shocks persists indefinitely, the time series will present a stochastic trend and past trend will not necessarily be useful to produce forecasts.

Finally, assessing the difference of a series from a benchmark allows us to provide advice on the choice of policy instruments available to policy-makers. When long-term differences are stochastic, policy mechanisms affecting economic actors in a uniform fashion would seem a rather blunt instrument. Ideally, policy instruments would need to take into account the evolution of the series and the peculiarity of the subsectors. On the other hand, when long-term differences are deterministic, a uniform policy instrument not subject to periodical reviews would seem suited to meet the policy-makers' objectives. It goes without saying that periodical reviews of these instruments can still be needed due to changes in the information set or in the objectives of policy-makers.

3 Literature Review

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From a conceptual point of view this paper is part of the branch of the economic literature assessing the convergence of time series. This line of enquiry is employed often, especially when assessing income per capita and prices of a certain good or a basket of goods. In these cases empirical studies have been motivated by the desire to verify theoretical propositions, i.e. respectively, the neoclassical growth models, the law of one price and the Power Purchasing Parity (PPP). Empirical studies have, however, assessed the existence of convergence of certain variables across sectors in fields where theoretical expectations on their convergence were less strong than those mentioned above. An example is provided by the employment rate across countries. Blanchard and Katz (1992) and Decressin and Fatas (1995)) are two authoritative studies in this field.

Three notions of convergence, namely β-, σ- and stochastic convergence, are normally used in empirical studies - see, amongst others, Lee et al. (1997), for a discussion. Another approach to the analysis of convergence of economic variables is based on a Markov chain transition matrix and the speed to an ergodic distribution – see Kakamu and Fukushige (2006) and Happich and van Lengerke (2007) for two recent applications. Going back to the notions of convergence normally used in the literature, β-convergence assesses the speed at which the variable of interest tends to its steady-state value. The estimate of the speed of convergence is assesses through time-series, panel, or cross-sectional regressions. The validity of the cross-sectional approach has been seriously put in doubt by Evans (1997). Bianchi and Menegatti (2007) discusses the potential pitfalls connected with the use of pooled and panel estimators. Convergence may be unconditional or conditional to some variables; steady-state growth rates can be common or member-specific (Lee et al. 1997). Cuaresima et al (2008) and Galvatildeo and Gomes (2007) are two examples of empirical studies analyzing the issue of β-convergence

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Sigma convergence, which focuses on the behaviour of the variance, is theoretically interesting if one believes that there is a common equilibrium and that the speed of convergence to steady-state outputs is the same (Lee et al. 1997). Gil-Pareja and Sosvilla-Riviero (2008) examines whether the law of one price holds in the European Union car market over the period 1995-2005. In order to measure the degree of price convergence, the coefficient of price variation of each car model across the European markets is regressed on a time trend and a constant. Sigma convergence occurs if cross-sectional dispersion decreases over time, i.e. coefficient on the time trend is negative and statistically significant. The authors find clear evidence of price convergence among the EU15 countries after 1999. In some articles, the existence of sigma convergence is assessed on the basis of unit root tests, i.e. with a methodology similar to the one employed in this article – see, among others, Blot and Serranito (2006) and Koukomelis (2008).

Finally, stochastic convergence focuses on the time series properties of the variables and assesses whether a time series observed for different economic agents, e.g. regions, countries or economic sectors, share a common trend. Stochastic convergence is normally tested by analyzing cointegration among economic series or the presence of unit roots. Jenkins and Madzaharova (2008) is a paper using cointegration tests, both univariate and panel, to asses the presence of stochastic convergence. In our study, the presence of stochastic convergence is investigated through unit root tests. De Siano and D'Uva (2006) and Lima and Resende (2007) are two examples of studies adopting this approach. Before surveying a number of studies from the energy literature, it is worth mentioning that the use of the word convergence, in any of three meanings described above, is not very common in the energy literature. As some readers might be wrongly misled to believe that the levels of energy intensities in different sectors become gradually similar, we prefer avoid the use of the term convergence when discussing the results of our study, and report

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our results by discussing the equivalent concept of long-term differences. In fact, two series are stochastically convergent when the long-term differences are deterministic, while they fail to be stochastically convergent when long-term differences are stochastic.

In the energy literature researchers have been assessing convergence between prices across markets, e.g. Robinson (2007), and prices of different products, e.g. Lanza et al (2005), and between per-capita levels of CO_2 emissions (Lee et al 2008). Robinson (2007) uses the concepts of β- and stochastic convergence to investigate the degree to which the ambition to create a single European electricity market, as set out in a number of legislative measures, has been practically achieved. In the case of stochastic convergence, the author applies the methodology we discuss in the next section. Stochastic-convergence, which is tested through an ADF test, is accepted in six out of nine instances. Neumann et al (2006) assess the β-convergence of natural gas prices in the European markets while allowing for time-varying parameters by using the Kalman filter. The dataset used by the authors comprises daily day-ahead prices observed over March 2000-February 2005 at three trading hubs, the British National Balancing Point (NBP), the Belgian Zeebrugge and the Bunde-Ounde hub at the German-Dutch border. In the case of the NBP and the Zebrugge, there is a clear trend towards convergence, arguably promoted by the interconnector between the English and the Belgian markets. On the other end the β-coefficient for the pair Zeebrugge–Bunde does not reveal any particular pattern of convergence.

Lee et al (2008) is very similar to our study with regard to the methodology and the findings. The authors investigate whether the long-tern differences among the per-capita CO_2 emissions of 21 OECD countries during the 1960–2000 period are stochastic or deterministic by using univariate tests assuming structural stability and the suite of tests proposed by Sen (2003) which allows for a break in the intercept and

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the slope. In the case of univariate tests the null of unit root is rejected only in about 15% of the cases. However, when using the F^{MAX} test, the unit root is rejected in 13 of the 21 countries assessed in the study. Unlike traditional unit root tests, when one controls for breaks, the results provide evidence that relative per capita CO_2 emissions are stochastically convergent.

It is worth pointing out that the findings of Lee et al (2008), i.e. strong influence of structural breaks on the assessment of convergence, are not uncommon in the literature. In Drine and Rault (2006), the empirical validity of the PPP can be confirmed only when employing a LM test allowing for breaks. A similar finding is discussed in Cuntildeado and Gracia (2006) with regard to the convergence of per-capita output of a number of East European countries towards the German and US level. Other examples of this pattern can be found in Galvatildeo and Gomes (2007) and Narayan (2006). However, it should be pointed out that employing unit root tests allowing for structural breaks is no guarantee for an increase in the rejection rate of the null hypothesis – see for example Lee (2006).

From the brief discussion above, we can conclude that the concept of convergence has been rarely assessed in the energy literature with the exception of price series observed in different markets or related to different products. This paper aims to fill this gap in the literature by extending the convergence analysis to the energy intensity of industrial subsectors. As far as we are aware, no analysis of the convergence of this variable using the approach described below can be found in the literature. In addition, we noticed that the modeling of structural breaks had quite an important effect on the results from the studies assessing the convergence of economic variables. We also discovered that the Lagrange-Multiplier unit root tests have never been applied to an energy dataset. This paper fills this methodological gap in the

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applied literature, which is a valuable undertaking if one bears in mind the superior performance (see below) of Lagrange-Multiplier unit root tests.

4 Methodological Approach

This paper follows the approach of Carlino and Mills (1993) where a series $Y_{i,t}$ is assessed relative to a benchmark Y_{bt}. The dependent variable of the study is therefore $y_{it}^d = Y_{it} - Y_{bt}$ rather than the levels Y_{it}. If the logarithms of the data are used, y_{it}^d is equal to the logarithm of the ratio between the series and the benchmark, which is normally set to be the average across the series in the dataset. One can further assume that the difference from the benchmark consists of a time invariant differential x_i, random short-run difference v_t, and the initial difference v_0. Breaks in the deterministic components can also be accommodated by the variable m_i. If the trending long-term differences are found to be deterministic, differences between a series and the benchmark can be written as

$$y_{it}^d = x_i + v_0 + \rho_i y_{it-1}^d + \beta_i t + \delta_i m_i + v_t \quad (1).$$

where t indicates a linear trend t. However, in case of trending long-term stochastic differences, (1) can be re-written as $y_{it}^d = x_i + v_0 + y_{it-1}^d + \delta_i m_i + v_t$, therefore imposing the joint restriction $\rho = 1$ and $\beta = 0$ in (1). The nature of the differences among the series Y_{it} and the benchmark Y_{bt} can be assessed by testing for the presence of unit roots in y_{it}^d. This analysis can be undertaken for each time series in the dataset separately or for the dataset as a whole by using panel tests. If there is a unit root, long-term differences between y_{it} and the benchmark are stochastic, as short-term random differences accumulate across time. If there is no unit root, short-

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term random differences dissipate and long-term differences are deterministic. In the case of the ADF tests, the testing regression can be written as

$$\Delta y_{it}^{d} = \mu_i + \beta t + \rho_i y_{it-1}^{d} + \sum_{j=1}^{k} c_j \Delta y_{it-j}^{d} + \varepsilon_{it} \ .$$

5 Data Description

Annual data on energy consumption is taken from IEA (2005), which provides information for the sectors listed in the first column of Table 1 for the 1970-2004 timespan. Data on the Gross Value Added (GVA) have been sourced from Office for National Statistics (ONS) (2006a) and ONS (2006b). As shown in the third and fourth columns of Table 1, GVA data are available at two different levels of detail[1]. The more aggregate time series match the timespan of the energy data but require aggregation of the last five sectors in column 1. On the other hand, the most disaggregated GVA time series (matching the energy taxonomy with the exception of Iron and Steel and Non-Ferrous metals which need to be aggregated) requires dropping eight observations, i.e. the time period spanned by the sample becomes 1978-2004. While using the longer sample is preferable for the power of the tests, one can also have concerns related to the difference among the sectors which need aggregation, i.e. the sectors in the last five rows of Table 1[2]. For this reason, the differences among industrial sectors were assessed in both samples, i.e. by using the

[1] Energy and GVA data are available separately for the sectors Wood and Wood Products, and Paper, Pulp and Print. The decision to consider these two sectors together is related to the quality of the data on energy consumption in the Wood and Wood and Products. Energy Consumption decreases from 127 TTOE in 1991 to 21 TTOE in 1992 while GVA decreased from 2783 to 2751 million pounds. The breaks in the series disappear when the energy consumption from Wood and Wood Products is added to Paper, Pulp and Print due to the considerable higher consumption of the latter.

[2] In fact, as shown in Figure 1b, the Metal sector has by far the highest energy intensity, i.e. twice as big as the second highest sector. When the metal sector is aggregated to other three sectors in OTH_1, see Figure 1a, the energy intensity is similar to that of Food and Tobacco.

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taxonomy in column 3 for the longer sample and that in column 4 for the shorter sample.

[INSERT TABLE 1]

The energy intensities can be observed in Figure 1. As can be seen, the Construction, Wood, Pulp, Paper and Print, Food and Tobacco, Textiles, Machinery and Transport Equipment have lower energy intensities than the average of the industrial sector. The Chemical, Non-Mineral Metal and Metal sectors have the highest energy intensities. Figure 2 displays the difference between the sectoral energy intensities and the average of the industrial sector. The time series of some sub-sectors presents a number of spikes mainly caused by sudden changes in the sub-sectors[3]. In the Food and Tobacco sector, the increase between 1980 and 1990 is due to energy intensity in the sector decreasing at a lower rate than in the other industrial sectors. The increase in the textile sector at the end of the sample is caused by the fact that a decrease in GVA is not matched by a corresponding change in energy consumption. Similarly to the Food and Tobacco sector, the time series for the Chemical sector in Figure 2 switches between two levels, namely the pre-1982 and the post-1989 levels. Energy Intensity in this sector almost halves between 1982 and 1989 – see Figure 1. As this reduction exceeds the decrease in the industrial sector, the time plot in Figure 2 presents a downward trend. Finally, the decrease in the time series for the Non-Metallic Mineral sector observed in the first few years and in the last 10 years of the sample is mainly due changes in energy consumption in the sector.

[3] Those occurring in 1970-72 and 1984 in the textile sector and in 1989 and 2003 in the mining sector are all caused by sudden changes in energy consumption unmatched by changes of the GVA. A sudden decrease in the energy consumption is also the cause of the marked decrease in the construction sector in the last two years of the sample.

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[INSERT FIGURE 1 AND FIGURE 2]

With regard to the subsectors aggregated together into the Other Industry sector in the 1970-2004 sample (see Figure 2d), the Metallic, Transport Equipment and Machinery sectors are relatively flat until 1995. A decrease in the Metallic sector can be observed thereafter. In the Transport Equipment sector, the sudden increase in 1984 and the decrease in 1988 in the relative energy intensity are caused by sudden changes in the energy consumption. Quite interestingly, the non specified industrial sector (OTH_2) shows increasing energy intensity over the whole observation sample.

While gradual changes in the level or trend of long-term difference could be explained by structural change in the sectors or by changes in the level or trends of factors affecting the energy intensity (e.g. energy price), it is worth stressing that a number of the sudden changes described above are likely to be caused by measurement errors and other limitations in the dataset. While we bear this point in mind, using a dataset published by international institutions seems more advisable than embarking on a subjective data adjustment process guided by uncertain and somewhat arbitrary criteria.

6 Univariate Testing with and without Structural Breaks

The presence of unit roots is tested by running the ADF, the PP test and a number of other tests. As both the PP and ADF tests suffer from low power, especially when the value of the parameter on the first autoregressive term is close to one or when the series is trend-stationary (see among others, DeJong et al (1992) and Campbell and Perron (1991)), two strategies have been followed in the literature to increase the power of the tests. The first approach exploits the identical covariance structures of forward- and backward-looking finite order stationary AR models; the other recurs to

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a non-OLS estimator in order to estimate the deterministic components of the univariate process. Among the tests using the first approach, this paper implements the DF^{MAX} (Leybourne 1995). The DF^{RMA} (Shin and So 2001), the DF^{GLS} (Elliott, Rothenberg and Stock 1996) and the M tests (Ng and Perron 2001) are three types of tests using a non-OLS estimators to compute the deterministic components in the series.

The results from the tests discussed above are shown in Table 2 for the 1970-2004 and 1978-2004 samples[4]. Overall, the results estimated over the two samples point at the time series being integrated of order one. The long-term difference in the construction sector can be judged deterministic in the shorter sample according to the M^{GLS} tests in the model with intercept only. In the same sample, the differences can be judged deterministic also in the Machinery sectors according to the DF^{RMA} and DF^{MAX} tests, and in the Metal sector according to the DF^{RMA} with intercept and trend – see Table 2. It should be borne in mind that the statistical significance in the table is determined by using the critical values computed with a number of observations closest to our sample among those published in the literature. While in the case of DF^{MAX} test we were able to use a critical value based on 25 observations, asymptotical critical values needed to be used in the case of the $\overline{M}^{GLS}$ tests. In the case of the ADF and PP tests we used critical values from MacKinnon (1996). However, as critical values simulated on the basis of the length of our sample would

[4] In the case of the $\overline{M}^{GLS}$, i.e. MZ_α, MZ_t, MSB and MP_T in the table, GLS detrended data are used to construct the series on which the test is run and the autoregressive spectral density estimator s^2_{AR}, as suggested in ERS (1996) and NP (2001). The Modified Akaike Information Criterion (MAIC) has been used to determine the lag in the estimation of s^2_{AR} and in the unit root regressions. When using the MAIC, the maximum lag was set at $l12$. The PP test was run for a bandwidth going from $l0$ to $l12$. The deterministic components in the ADF and DF^{GLS} tests were chosen according to the value of the Schwarz and Akaike Information Criterion (SC and AIC, respectively). The specification selected for the ADF test is also used for the PP, DF_{MAX} and the DF^{RMA} tests while that selected for the DF^{GLS} test is also used for the $\overline{M}^{GLS}$ tests.

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be higher than those we used in Table 2, our results should be considered optimistic, in the sense that a lower number of rejections would likely have been obtained if simulated critical values had been used. Our use of tabulated rather than simulated critical values can be the cause of the reason why the null hypothesis for the construction sector is rejected in the shorter sample according to the $\overline{M}^{GLS}$ test. Overall, from Table 2 we conclude that long-term differences are stochastic. As using simulated critical values would not affect this conclusion, critical values are not simulated.

[INSERT TABLE 2]

The results from unit root tests can be misleading when a structural break goes unaccounted, the so-called Perron-effect (Perron 1989). Considering the breaks discussed in Section 5 (see also Figure 2), it is therefore unclear if the failure to reject the null hypothesis in the case is due to the processes being I(1) or to the presence of structural breaks. Univariate tests allowing for structural breaks have found extensive implementation in the energy literature. Most papers, see for example Lanne and Liski (2004), implement ADF-based tests, like those from Zivot and Andrews (ZA) (1997), and Lumsdaine and Papell (LP) (1997). However, both tests tend to select T_B-1 as the breakpoint, where T_B is the real breakdate. In addition, when a break occurs under the null hypothesis, the size of the tests markedly increases (Lee and Strazicich 2001). In order to account for these two problems Lee and Strazicich (LC) (2004) and LC (2003) extend the Lagrange Multiplier procedure of Schmidt and Phillips (1997) to DGPs with one and two structural breaks, respectively. The finite sample properties of the LM-based tests are discussed in Lee (1997). While in the ADF-based test no break is assumed under the null, as the critical values of the test would otherwise depend on the location and magnitude of the break, the LM statistics are invariant to these nuisance parameters (LC 2003). Unlike the ADF-based tests, LM

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unit root tests will not spuriously reject the unit root hypothesis if there is a break under the null. Following a number of articles in the applied literature, for example Galvatildeo and Gomes (2007) and Narayan (2006), this study implements the LM tests only on the basis of the limitations discussed above for the ADF-based tests.

For the LM test with one break we ran the model allowing for a break in the intercept (model A) and the model allowing for a break in the intercept and slope (model C). Similarly, in the case of the LM test with two breaks, we ran the model allowing for breaks in the intercept (model AA) and the model allowing for breaks in the intercept and slope (model CC). Model selection was implemented on the basis of the value of the information criteria. When the Akaike and the Schwarz information criteria failed to agree on which model fits the data best, two models are reported. Before discussing the results from the tests, it is worth mentioning that in the case of the LM tests run on model CC, our samples implied running a regression with 35 and 27 to estimate a number of parameters going from a minimum of six to a maximum of ten, depending on the number of lags of the differenced dependent variable added to the regression. Although it would be preferable to have a higher number of observations, we however notice that the estimation of a model with two breaks over a sample spanning a time period similar to ours is not uncommon in the literature – see for example Narayan (2005). In addition, despite the many limitations of panel unit root testing described in the next section, we also implement a panel LM test which can be considered an indirect way to validate the results from the tests discussed in this section.

Results from the LM tests differ somewhat from those presented in Table 2. As can be seen in Table 3, in 38% and 45% of the industrial sectors long-run differences can be considered deterministic in the longer and in the shorter sample, respectively. Comparing the results from the two samples, one can notice that breakpoints tend to

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be the same if the breakpoint in the longer sample falls in the time window where breakpoints are allowed to occur in the shorter sample. When using the LM test allowing for a break, only in two instances long-term differences among the subsectors can be considered deterministic in the longer sample. In the shorter sample however this occurs in about 55% of the cases. When using the LM test allowing for two breaks, in 50% and 73% of the cases the long-term differences can be considered deterministic in the longer and the shorter sample, respectively. With regard to breakpoints, in six instances the LM with one and two breaks over the longer sample select a common breakdate. In the shorter sample, the number of series sharing a common breakdate rises to eight. It is fair to conclude that the application of univariate tests allowing for structural breaks has reversed the conclusions of the univariate and panel unit root tests discussed in Sections 4 and 5.

[INSERT Table 3 HERE]

Figure 3 shows the breakpoints selected by the models allowing for two breaks displayed in Table 3. It can be seen that in both samples, breakdates can be grouped into three clusters which in the case of the shorter sample go from 1983 to 1988, from 1990 to 1993 from 1997 to 1999. These brakes are likely to be caused by a combination of changes in the economic conditions and energy price fluctuations. The first group of breaks can be imputed to the recession affecting the British industrial sector in the eighties – the real term GVA of the manufacturing sector went back to its 1979 value only in 1987 (ONS 2007). It is also worth noting that the energy price in the industrial sector has been rather unstable over the same time period, reaching its peak in 1985 and crashing the following year (DTI 2005). Also the breaks in the following group might be influenced by the milder and shorter recession of the early nineties, i.e. the real term GVA of the manufacturing sector went back to its 1990 value only in 1994. However, energy price were rather stable.

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Finally, the time period over which the last group of breaks occurred, 1997-1999, was not really remarkable in terms of economic conditions, with the GVA growing at a rate comparable to that observed in the previous couple of years (ONS 2007). The trend in the energy price however changed suddenly in 1996 when the decreases started in 1986 finally came to an end; prices stayed stable until 2003 before heading upwards in 2004 (DTI 2005). It should also be borne in mind that breaks in the series used in this study can be caused by limitations in the dataset. While there seems to be some truth in this argument, as discussed in Section 5, it remains unclear how the data should be adjusted. Overall, using official data seems preferable to embarking on a somewhat arbitrary revision of the data. If breaks are due to the limitations of the dataset, modelling structural beaks can be considered a convenient approach to take into account limitations in the quality of data available to researchers.

[INSERT Figure 3 ABOUT HERE]

7 Panel Testing

We also assessed whether the results from univariate tests discussed above are confirmed by panel unit root tests. In the energy literature, Chen and Lee (2007), Narayan and Smyth (2007) and Tauchmann (2006) are few examples of papers implementing panel unit root tests. In this article we implement the LLC test (Levin, Lin and Chu (LLC) (2002)), the Breitung test (Breitung 2000), the Hadri test (Hadri 2000), the tests from Maddala and Wu (1999) and Choi (2001) (labelled Fisher and Choi in the table below), the test from Im, Pesaran and Shin (IPS) (2003) and, finally, the CIPS test of Pesaran (2007). As most of these tests have been already discussed in a number of applied papers, rather than reviewing the tests it seems more useful to discuss the limitations of panel unit root testing.

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The first limitation is related to the alternative hypothesis. In the case of homogenous tests, the alternative hypothesis is rather restrictive, i.e. all series are stationary and have the same AR(1) coefficient. Among the tests in Table 4, the LLC, the Hadri and the Breitung tests are affected by this criticism. In the case of heterogeneous tests, under the alternative hypothesis some series are allowed to have unit roots while others are allowed to be stationary and have different AR(1) coefficients. While this makes heterogeneous tests more appealing, the less restrictive alternative hypothesis makes the results from the tests inconclusive. When rejecting the null hypothesis, one can simply conclude that a significant fraction of the cross section units is stationary. The panel tests do not provide information on the size of this fraction or the identity of the cross section units that are stationary (Breitung and Pesaran 2005). Among the tests in Table 4, this criticism applies to the Fisher, Choi, IPS, CIPS and ILT tests.

A limitation which applies to all tests in Table 4, with the exception of the ILT test of Im, Lee and Tieslau (ILT) (2005) is related to the fact that time series are assumed to be structurally stable. Only in the ILT test, breaks are allowed under the null and the alternative hypothesis. Another test allowing for structural breaks, which is not implemented in this study, is discussed in Carrion-i-Silvestre, Del Barrio-Castro and Lopez-Bazo (2005). The panel LM statistic can be computed by standardizing the average of the univariate LM statistics by their variance. Another limitation which applies to all tests in Table 4, with the exception of the CIPS test, and to all tests implemented so far in the energy literature with the partial exception of Chen and Lee (2007), is related to the correlation among the series comprised in the dataset, also known as cross-sectional dependence. Correlation can be tackled by demeaning the data - see among others IPS (2003) – although this approach works only when correlation is constant. The feasible generalised least squares (SUR) method can be applied to more general types of correlation (O'Connell 1998) although it can be used only for small N (less than 10) and large T (Breitung and

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Pesaran 2005), and only when cross-sectional correlation occurs between the stationary components (Wagner 2005). Another approach for dealing with cross-sectional dependence assumes that correlation enters the model through common factors. After estimating the common factors, test statistics can be obtained by averaging Dickey-Fuller tests (heterogeneous tests) from defactored data or by pooling defactored time series (homogenous tests). This paper implements the CIFS test of Pesaran (2007), i.e. an extension of the IPS test to allow for the presence of one stationary factor. The CIPS statistic is obtained by averaging the t-statistics from the cross-sectionally augmented DF regression. Other tests are presented in Bai and Ng (2004), Moon and Perron (2004) and Phillips and Sul (2003).

We conclude this brief discussion of the limitations of panel unit root tests with a criticism that applies to all panel tests. This is related to the argument that panel unit root tests can be used to increase the power of univariate tests. However, as different null and alternative hypotheses are tested when running univariate and panel unit root tests, the power of the two procedures cannot be compared – see Maddala and Wu (1999). Bearing this rather lengthy list of limitations, we implement the panel unit root testing mainly to obtain confirmation of our results for the univariate LM tests discussed above. Confirmation of those results is beneficial especially in the case of the models allowing for two breaks in the short sample, where the estimation procedure could be negatively influenced by the relatively low number of observations available for the estimation.

The table below summarises the results of the panel unit root tests computed in this study. The bandwidth lag in the Hadri, the LLC and in the tests based on the PP tests (Fisher Chi and Choi Z in the table) has been selected by using the Newey-West criterion.. Among the tests assuming structurally stable time series, only the Breitung test rejects the null hypotheses in the case of the model with intercept. The CIPS test

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is not statistically significant in either of the samples used in this study. However, in the shorter sample, the statistics fall very close to the 10% critical value. The application of the panel LM test of ILT (2005) supports the results of the univariate tests discussed in the previous section. The statistics in the table have been computed on the basis of the observations in our sample, i.e. 35 and 28 respectively. Long-term differences among the energy intensity are deterministic, regardless of the breaks in the model. However, from the table it can be concluded that assuming breaks in the intercept only tends to lower values of the test statistics compared to models with breaks in the intercept and trend. Similarly, the value of the tests run on models with two breaks is higher than the value of the tests from models with one break only. Similarly to Costantini and Arbia (2008) and Lean and Smyth (2007), panel unit root tests confirm the results obtained from univariate tests. Despite the limitations of panel unit root testing procedure, we can therefore conclude that modelling breaks has a very strong influence on our results and that the limited span of our sample and the consequent few observations available in univariate LM tests with two breaks does not produce different results from those we could observe when using a panel procedures.

[INSERT TABLE 4]

8 Discussion

This paper has assessed whether long-term differences among energy intensities of industrial subsectors are stochastic or deterministic. The spirit of our findings is similar to Gaffeo et al (2005) where inference appears to be strongly dependent on the type of tests used, so that conclusions reached at early stages of the testing procedure can be discarded at subsequent stages. In the case of this paper, if the analysis had not included tests allowing for breaks, we would have concluded that the long-term differences of energy intensities among industrials sectors were stochastic. However,

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after allowing for structural breaks, the opposite conclusion can be reached. With few exceptions, long-term differences can be considered deterministic. The findings from our paper are similar to those from Chen and Lee (2007), Lee et al (2008) and Cuntildeado and Gracia (2006), as the modelling of structural breaks is found to be the determining factor in judging the stationarity of the time series under analysis.

When applying the LM tests our results are rather sensitive to the number of breaks allowed in the testing procedure, especially over the 1978-2004. In presence of contrasting results from the tests allowing for one break and those with two breaks we overall lean towards the latter. In fact, as discussed in Gadea et al (2004), the inference on unit roots when the model is underparameterised (e.g. the time series has two breaks but only one is modelled) will be biased toward the acceptance of the null hypotheses. Although estimating model with redundant breaks reduces the power of the tests, the loss of power is much more serious when the testing procedure does not allow for a sufficient number of breaks. The lack of sufficient breaks in the testing procedure could also be the cause of our failure to reject the null hypothesis in the case of the Textile and Leather, and the Wood and Wood Product, and the Mining and Quarrying sectors. With regard to the last sector, it is interesting to notice that its long-term differences from the benchmark are stochastic in the longer sample but deterministic in the shorter sample. Following Perron (1989), this can be taken as evidence that an additional break takes place in the longer sample, probably around 1977 – Figure 2. From the figure one can also see that the time series for the Textile and Leather, and the Wood and Wood Product sectors is rather irregular. This hints at the possibility that if we had more observations, a tests allowing for a higher number of breaks would probably reject the null hypothesis of unit root. A flexible number of breaks can be modelled by a finite Markov chain of the type introduced by Hamilton (1989). It is also interesting to notice that the long-term differences of the residual sector, i.e. OTH_1 and OTH_2 in Table 1, cannot be considered deterministic in

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either the short or the log sample. This could probably be due to the fact that the residual sector comprises a number of subsectors which are very different from each other. In fact when the subsectors comprised in the OTH_1 sectors are modelled separately in the shorter sample, in three out of the four instances the long-term differences can be considered deterministic.

Going back to the motivation of our study, our analysis discovered that the the trend of long-term differences among the energy intensity of industrial subsectors changes occasionally, i.e. only at the occurrence of structural breaks in the deterministic component. This implies that the future movements of the long-term differences can be predicted on the basis of past behaviour. However, this is true only if one is ready to assume that the series will be structurally stable over the forecast horizon. The frequency of the breaks, i.e. about one every fifteen years, makes this assumption acceptable overall.

The policy implications of this study are related to the timing and frequency of policy interventions and to the policy instruments which can be used. As long-term differences among industrial sectors are mainly deterministic, short-term random difference dissipates across time. For this reason, policy makers with an interest in the series following a certain time pattern do not need to intervene at any single minor departure of the series from the desired trend. As pointed out by Chen and Lee (2007) and Narayan and Smyth (2007), in this case government should not be concerned with short-term fluctuations when implementing energy policies. In fact, if they want to affect the evolution of the series, policy makers will need to implement prolonged policy measures able to affect the deterministic components.

In relation to the type of instruments which can be used by policy makers, we can conclude that policies taking into account the evolution of the series and the

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peculiarity of the economic actors cannot be justified on the basis of our analysis. In fact, the presence of long-term deterministic differences among the series supports the adoption of policy instruments which are applied across productive sectors without frequent changes. Among the policies in the energy sector, energy and CO_2 taxes applied to all industrial subsectors would be an example of this type of instrument. While the analysis discussed in this paper does not consider the effects on the competitiveness of the industrial sectors, we can conclude that it is not possible to dismiss the introduction of these taxes on the basis of the peculiarity of some industrial subsectors. In addition, if there is a relationship between the supposed adverse effects of these taxes and the difference in energy intensities across sectors, the importance of these effects is likely to reflect the deterministic nature of the series assessed in this study and its long-term pattern. A final advice to policy-makers is related to the caution needed when drawing conclusions from the use of a narrow set of statistical methodologies. As discussed above, the results from tests allowing for breaks are opposite to univariate and panel tests assuming structural stability. Policy advice from the latter would be completely different from the conclusions drawn from this article.

In this study, modelling breaks has turned out to be a rather important issue. Breaks in the long-term differences can be due to time-varying and sector-specific factors which are not directly taken into account in this study. Alternatively, structural breaks can be caused by a change in the importance of subsectors comprised in the industrial sectors assessed in this study, provided that these subsectors have different energy intensities (e.g. pharmaceuticals and base chemicals in the chemical sector). Estimated breakdates seems to have been influenced by changing economic conditions, i.e. the recessions in the eighties and early nineties, and fluctuations in the energy price, notably the 1986 crash and the level off of the price in 1996. It is also possible that some of the breaks in the series are caused by limitations in the dataset,

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as discussed in Section 5. If this argument is right, modelling structural beaks can be considered a convenient approach to take into account limitations in the quality of data available to researchers.

9 Conclusions

From our study we can conclude that long-term differences in the energy intensities of the British industrial subsectors are deterministic, after allowing for structural breaks in the series. The few cases where the null hypothesis of stochastic long-term differences could not be rejected are probably due to our testing procedure which cannot take into account more than two breaks in the series or to the fact that some of the sectors assessed in this study comprise a number of subsectors with a very different technological profile. The implication from our study is that the trend of long-term differences changes only occasionally, i.e. only at the occurrence of structural breaks in the deterministic components. For this reason, future movements of the long-term differences can be predicted on the basis of past behaviour. From a policy point of view, our analysis implies that policy makers do not need to intervene at any single minor departure of the series from the desired trend. In addition, our analysis supports the adoption of policy instruments which are applied across productive sectors without frequent changes. Among the policies in the energy sector, energy and CO_2 taxes applied to all industrial subsectors would be an example of this type of instrument.

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Industrial subsectors	NACE code	Acronym	
		1970-2004	1978-2004
Mining and Quarrying	13 and 14	MIN	MIN
Food and Tobacco	15 and 16	FT	FT
Textile and Leather	17, 18 and 19	TXT	TXT
Wood and Wood Products	20	WPP	WPP
Paper, Pulp, and Printing	21 and 22		
Chemical and Petrochemical Industry	24	CHE	CHE
Non-Metallic Minerals	26	NMM	NMM
Construction	45	CON	CON
Iron and Steel	27.1 + 27.31	OTH_1	MET
Non-Ferrous Metals	27.2 + 27.32		
Transport Equipment	34 + 35		TRA
Machinery	28, 29, 30, 31 and 32		MAC
Non Specified Industry	25, 33, 36 and 37		OTH_2

Table 1 *Industrial sectors modelled in the 1970-2004 sample and in the 1978-2004 sample. In the first sample the Iron and Steel, the Non-Ferrous Metals, the Transport Equipment, the Machinery and the Non Specified Industry sectors are grouped together (acronym OTH_1). In the second sample, the Iron and Steel and the Non-Ferrous Metals are grouped together (acronym MET). In both samples, the Wood and Wood Products and the Paper, Pulp, and Printing are grouped together (acronym WPP).*

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1970-2004																
	MIN		**FT**		**TXT**		**WPP**		**CHE**		**NMM**		**CON**		**OTH_1**	
ADF	-1.99/-2.43	I/T	-1.05/-1.83	I/T	-1.58	I	-1.11	T	-1.91	T	-2.15	I	0.06	T	-2.39	T
PP	-1.96/-2.43	I/T	- 1.14/-1.97	I/T	- 1.80	I	- 1.26	T	-3.01	T	-2.42	I	1.44	T	- 2.42	T
MZ_α	- 10.69	T	-5.24	T	-5.84	T	-3.31	T	-4.67	T	0.07	I	-31.19	T	-8.03	T
MZ_t	- 2.08	T	-1.62	T	-1.66	T	-1.17	T	-1.52	T	0.02	I	-3.45	T	-1.92	T
MSB	0.19	T	0.31	T	0.28	T	0.35	T	0.33	T	0.35	I	0.11	T	0.24	T
MP_T	9.58	T	17.38	T	15.51	T	25.14	T	19.45	T	12.76	I	5.58	T	11.57	T
DF^{GLS}	-2.58	T	-1.80	T	-1.90	T	-1.25	T	-1.56	T	-0.54	I	-1.29	T	-2.34	T
DF^{MAX}	-1.99/-2.43	I/T	-1.05/-1.63	I / T	- 1.58	I	- 1.11	T	-1.20	T	-1.56	I	0.06	T	-2.35	T
DF^{RMA}	-1.36/-1.45	I/T	-0.29/0.51	I / T	-0.05	I	0.86	T	1.00	T	0.52	I	1.67	T	-0.62	T

1978-2004										
	CON		**MET**		**TRA**		**MAC**		**OTH_2**	
ADF	1.19	T	0.19 /-0.01	I/T	-0.94 /-1.77	I/T	-2.54	I	-2.41	T
PP	1.52	T	0.71 /-2.25	I/T	-0.77 /-1.80	I/T	-2.57	I	-2.33	T
MZ_α	-21.39 $^{(**)}$/ -.76	I/T	-11.39	T	-6.33	T	-9.37	T	-7.22	T
MZ_t	-2.49 $^{(*)}$ / -0.39	I/T	-2.22	T	-1.58	T	-2.16	T	-1.87	T
MSB	0.12 $^{(**)}$/ 0.22	I/T	0.20	T	0.25	T	0.23	T	0.26	T
MP_T	3.49$^{(+)}$/ 20.33	I/T	8.80	T	14.31	T	9.74	T	12.67	T
DF^{GLS}	0.14 / -0.49	I/T	-3.22 $^{(*)}$	T	-2.23	T	-2.77	T	-2.39	T
DF^{MAX}	1.19	T	0.19/-0.01	I/T	-0.94/-0.35	I/T	- 2.54 $^{(*)}$	I	-2.08	T
DF^{RMA}	2.33	T	1.50/-4.44 $^{(**)}$	I/T	-0.36/-0.27	I/T	-2.41 $^{(*)}$	I	-0.29	T

Table 2 *Results from the unit root tests listed in the first column of the tables over the 1970 -2004 and the 1978-2004 sample. In the case of the latter, the table shows only the sectors grouped under the OTH_1 acronym in the longer sample and the Construction sector, i.e. the only sector presenting different results across samples. The list of sectors described by the acronyms in the first row of the table can be seen in Table 1. Key: ADF = Augmented Dickey Fuller; PP = Phillips Perron; MZ_α = Modified Z_α test; MZ_t = Modified Z_t test; MP_T = Modified Point Optimal test; MSB = Modified R_1 statistics. The symbols $^{(+)}$, $^{(*)}$ and $^{(**)}$ indicate statistical significance at the 10, 5 and 1% significance level. I and T indicate the model selected by the information criteria, i.e. intercept only (I) or an intercept and trend (T). Both models are reported when the information criteria were inconclusive on the choice of the model.*

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1970-2004							
	LM – 1 break	**Breakdate**	**Model**	**LM – 2 breaks**	**Breakdates**	**Model**	
MIN	-3.87	1998	C	-4.02	1996	1998	CC
FT	-3.42	1990	C	-5.86 (**)	1979	1990	CC
TXT	-3.46	1983	C	-2.90	1977	1983	AA
WPP	-2.88 / - 3.14	1991 / 1979	A / C	- 3.06 / -4.56	1977 / 1977	1991 / 1990	AA / CC
CHE	-3.92 (+)	1988	A	-5.54 (**)	1985	1988	AA
NMM	-2.77	1989	C	-5.68 (*)	1976	1987	CC
CON	-6.27 (*)	1998	C	-6.57 (**)	1991	1998	CC
OTH_1	-2.86	1980	A	-3.03	1980	1983	AA

[CONTINUE]

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1978-2004							
	LM – 1 break	**Breakdate**	**Model**	**LM – 2 breaks**	**Breakdates**	**Model**	
MIN	-3.43	1999	C	-5.73 (*)	1988	1999	CC
FT	-3.83 (*)	1990	A	-3.96 (+)	1990	1998	AA
TXT	-2.43	1983	C	-2.86	1983	1997	AA
WPP	-3.44	1999	C	-3.10	1984	1991	AA
CHE	-3.29 (+)	1988	A	-4.57 (**)	1985	1988	AA
NMM	-4.89 (+)	1987	C	-6.10 (*)	1987	1993	CC
CON	-4.63 (+)	1998	C	-6.93 (**)	1990	1998	CC
MET	-5.14 (**) / - 6.33 (**)	1991 / 1985	A / C	-6.62 (**)	1985	1991	CC
TRA	-2.62 / - 3.46	1995 / 1987	A / C	-5.75 (*)	1983	1999	CC
MAC	- 4.97 (+)	1993	C	-5.43 (+)	1993	1998	CC
OTH_2	-2.46 / - 4.41	1985 / 1993	A / C	-2.96	1983	1988	AA

Table 3 *Results for the LM test with one and two breaks. The symbols (+), (*) and (**) indicate statistical significance at the 10, 5 and 1% significance level. The list of sectors described by the acronyms in the first column of each table can be seen in Table 1. For each test the tables show the value the test statistic, the estimated breakdate and the model selected by the two information criteria. The letters A and C indicate the model with a break in the intercept and with a break in the intercept and trend, while the letters AA and CC indicate the model with two breaks in the intercept and with two breaks in the intercept and trend, respectively. Two models are reported when the information criteria were inconclusive on the choice of the model.*

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	1970-2004		1978-2004	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
Homogenous tests				
LLC	2.39	2.53	2.52	0.19
Breitung	- 2.06 (*)	1.42	-2.73 (**)	0.36
Hadri Z	5.48 (**)	4.75 (**)	9.04 (**)	5.37 (**)
Heterogeneous tests				
PP Fisher Chi	9.87	12.40	9.77	16.57
PP Choi Z	1.46	1.53	3.18	1.21
ADF Fisher Chi	8.68	8.67	8.31	10.56
ADF Choi Z	1.50	1.46	3.30	2.71
IPS	1.35	1.46	2.99	2.27
ILT – 1 break	-2.06 (*)	7.42 (**)	-5.27 (**)	-11.79 (**)
ILT – 2 breaks	-4.73 (**)	-15.44 (**)	-8.61 (**)	-18.78 (**)
Tests allowing for cross-section dependence				
CIPS	- 1.20	- 1.82	-1.08	-2.68

Table 4 *Results from the panel tests for the two samples assessed in this study. The tests listed in the first column of the table are all unit root tests with the exception of the Hadri Z test which is a stationary test, i.e. the series is assumed stationary under the null hypothesis. The symbols (+), (*) and (**) indicate statistical significance at the 10, 5 and 1% significance level. The CIPS statistic for the model with intercept and trend over the longer period falls very close to the 10% critical value, i.e. -2.73.*

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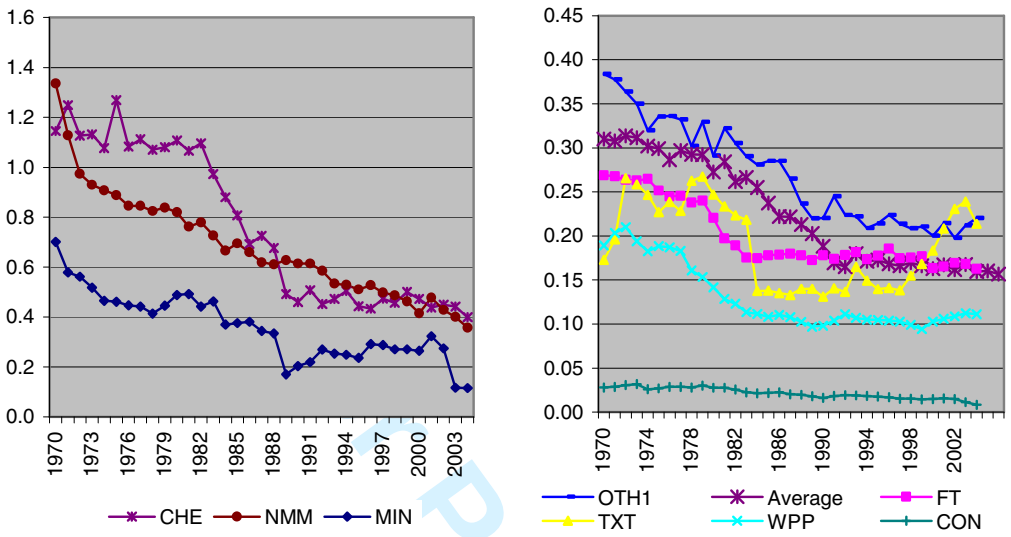

Figure 1a 1970 - 2004 *Energy intensity of the industrial subsectors assessed in this study. The list of sectors described by the acronyms in the figure column can be seen in Table 1.*

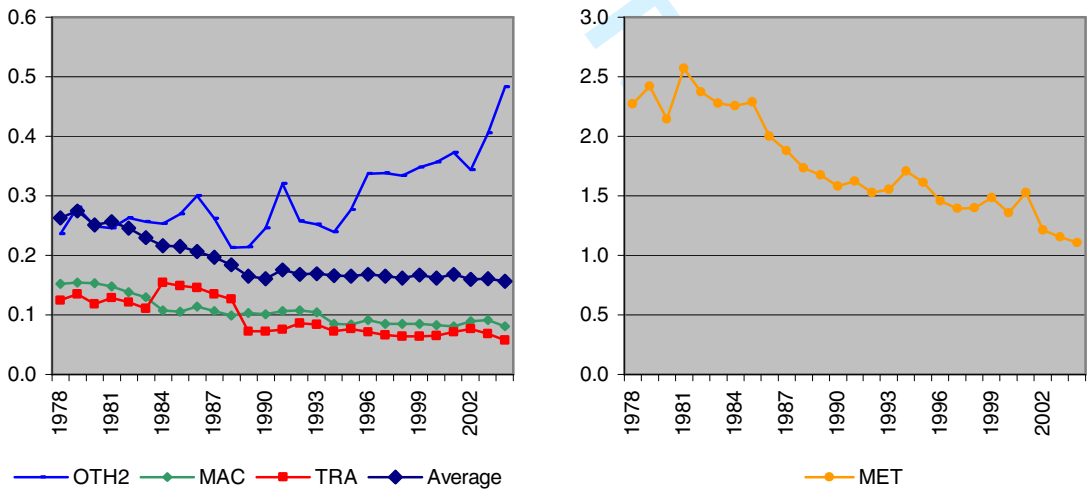

Figure 1b 1978 – 2004 *Energy intensity of the industrial subsectors. The list of sectors described by the acronyms in the figure column can be seen in Table 1.*

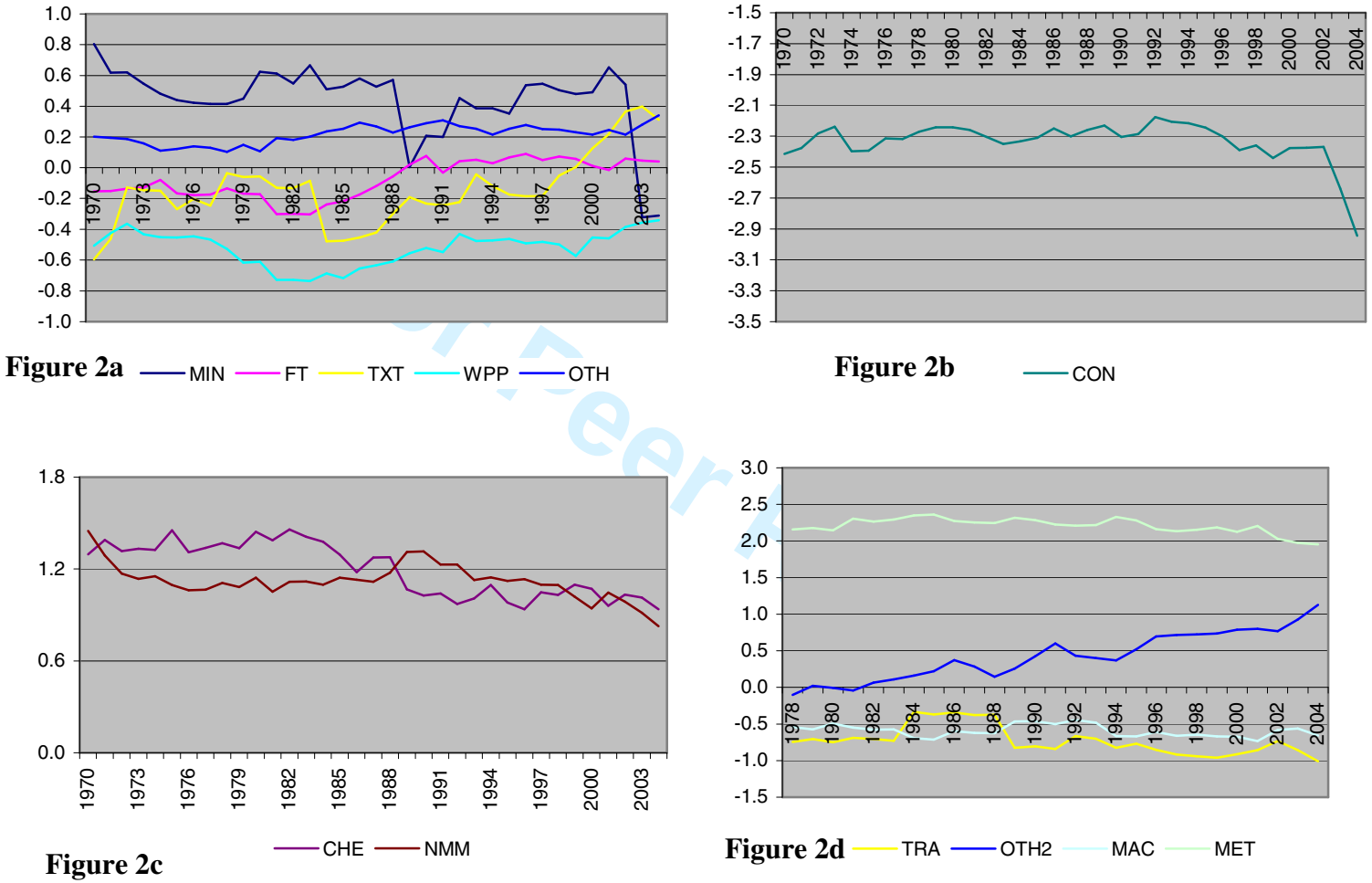

Figure 2 *Difference between energy intensity in the subsectors assessed in this study and the energy intensity in the industrial sector as a whole. Figure 2a, Figure 2b and Figure 2c show the time series for the sector assessed over for the 1970-2004 sample while Figure 2d shows the time series fro the additional sectors assessed over the 1978-2004 sample. The list of sectors described by the acronyms in the figure column can be seen in Table 1.*

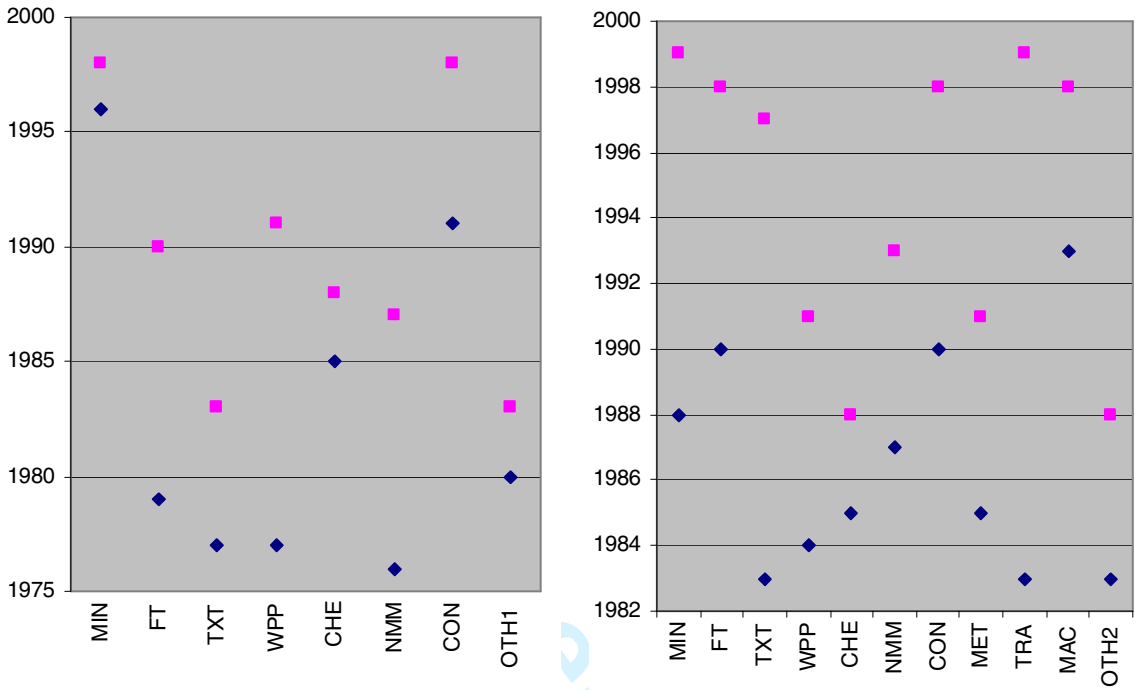

Figure 3 *Breakdates estimates by the models allowing for two breaks presented in Table 3. The figures on the left presents the breakpoint estimated over the 1970-2004 sample while the figure on the right presents those estimated over the 1978-2004 sample The list of sectors described by the acronyms in the figure column can be seen in Table 1.*