Applied Econometrics and a Decade of Energy Economics Research

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Abstract
Developments in applied econometrics, particularly with regard to unit root tests and cointegration tests, have motivated a rich empirical literature on energy economics over the last decade. This study reviews recent developments in time series econometrics applications in the energy economics literature. We first consider the literature on the integration properties of energy variables. We begin with a discussion of the implications of whether energy variables contain a unit root and proceed to examine how results differ according to the specific unit root or stationarity test employed. We then proceed to examine recent developments in the literature on cointegration, Granger causality and long-run estimates between (disaggregated) energy consumption and economic growth. We review both single country and panel studies and pay particular attention to studies which have expanded the literature through adding variables such as financial development and trade, in addition to energy consumption to the augmented production function, as well as studies which have extended the literature through examining disaggregated energy consumption by type. In each case we highlight best practice in the literature, point to limitations in the literature, including econometric modelling challenges, and suggest recommendations for future research. A key message of our survey is that the profession needs to guard against ‘overload’ of research in these areas as most applied studies are no longer adding anything more to what is already known.
1. Introduction

Developments in applied econometric estimation methods have been the catalyst for a rich body of applied energy economics research. Judging by papers accepted, and published, in leading energy economics journals, this trend is gaining momentum. There is a need to take stock of this literature. There is a need to review whether, at least in the most popular strands of the energy economics literature, greater volume of applied work is adding anything new. If it is making new contributions—this is welcomed, but if it is not, then future directions of research need to be reconsidered. This paper is a response to the growing energy economics literature motivated by new developments in applied econometrics. This paper not only addresses whether additional applied research is adding new insights to what is already known in two of the most popular fields in the energy economics literature, but also offers several directions for future research, allowing the profession to develop, and expand, upon the rich body of literature that it has so successfully developed.

We focus on two specific strands of the energy economics literature that have their origins in applied econometric methods. Specifically, our focus is on (a) integration properties of energy variables and (b) cointegration and Granger causality analysis. So much growth in energy economics research has been documented that a need to undertake a stocktake of this literature is not only timely but, hopefully, will guide future research in energy economics. In certain strands of the energy economics literature, it seems as if applied work is no longer making any new contributions and throwing any new light to what is already known (see also Karanfil, 2009). It is this ‘overload’ of research in certain fields against which the literature needs to guard.
Our review of the literature suggests two messages, which have important implications for existing and future research in energy economics based on new developments in applied econometrics. First, there is largely a consensus in the unit root literature that most energy type variables are stationary if tests utilize sufficiently large time-series data. This is confirmed by panel data models that examine the same unit root null hypothesis. Because panel data models have the advantage of having more power to reject the null hypothesis—a power gain that results from pooling of time-series components of a panel with its cross-section—almost all panel data unit root models with structural breaks reveal clear evidence that energy variables are stationary. It is imperative to assign greater weight to panel data models of unit root tests, as opposed to time-series models, because unit root models function parsimoniously when they are imposed on large sample sizes. Typically most energy type variables will have 30-40 years of annual data, which, particularly when the literature uses the relatively more popular structural break unit root models, is insufficient for unit root models to function precisely. Panel data models are a perfect response to this concern with time-series models. Our main message here is that the energy unit root literature has reached a point of consensus and unless off course there are new developments in unit root tests that suit the application of energy variables, there is perhaps not much to gain from additional applications of unit root tests.

Second, when we ask whether cointegration between energy variables and non-energy variables exists, the answer is overwhelmingly affirmative. Therefore, existence of a long-run relationship between energy variables and non-energy variables has become somewhat of a stylised fact. By comparison, there is no consensus when it comes to interpreting evidence on Granger causality, for which the evidence is mixed.
The mixed findings for Granger causality reflect several factors, including institutional differences between countries, model specification and econometric approach. With respect to model specification and econometric testing, there are at least two important considerations. One is that Granger causality is almost always tested in a multivariate framework, and since the sample size to begin with is already small, a multivariate treatment leads to loss of degrees of freedom. The second concerns the choice of lag length in a Granger causality model. Despite being chosen based on a lag length selection criteria, if the selected lag length is high, the model will be problematic since the sample period of estimation is already small and this results in an over-parameterised model. Ideally, a multivariate model should be used (see Payne, 2010). However, such an empirical specification assumes a large sample size. Typically, in applied energy economics literature, this is hardly the case.

In the absence of large historical time-series data, an alternative framework in which to consider Granger causality is bivariate models, as, for example, in Narayan and Popp (2012) and Narayan et al. (2010). There is obviously a trade-off. Within a bivariate framework, concern relates to problems associated with omitted variable bias, while, with a multivariate model the concern is with over-parameterisation and loss of degrees of freedom, which contributes to estimation error.

One could argue that to obviate the small sample and omitted variable biases, one should use a panel Granger causality model. This will be suffice to the extent that the objective is to examine a group of countries, for a panel Granger causality model will not reveal anything about the causality relationship for individual countries that make
up the panel. In sum, a panel data model will not be appropriate if the research question, and resulting policy implications, focus on results for individual countries.

The rest of the paper is set out as follows. Section 2 is about integration properties of energy variables. It begins with an analysis of motivation and implications, reviews the literature, discusses what constitutes the ‘state-of-art’ in the field and concludes with an agenda for future research. These steps are repeated in section 3 on the subject of cointegration, Granger causality, and long-run estimates. The final section concludes by reiterating the main implications and messages in the paper.

2. Integration properties of energy variables

Motivation and implications

The main motivation for testing for a unit root in energy consumption or production is to ascertain whether shocks have permanent or temporary effects. If energy consumption or production contains a unit root, shocks will have permanent effects. If energy consumption or production is stationary, a shock will result in only a temporary deviation from the energy variable’s long run growth path (Smyth, 2013).

There are several implications stemming from whether shocks to energy variables are permanent or temporary (Narayan & Smyth, 2007; Smyth, 2013). The major implication is whether the relevant shock represents a policy change designed to reduce consumption of fossil fuels or promote consumption of renewable energy. If fossil fuels contain a unit root, policies designed to reduce policy consumption will be effective because the negative shock induced by the policy change will be persistent. If renewable energy contains a unit root, policies designed to induce permanent
changes, such as renewable portfolio standards, will be more effective than policies designed to induce temporary changes, such as tax incentives (Barros et al., 2012).

There are several other implications as well. First, if energy is integrated into the real economy, one can expect that following a shock to energy consumption or production, that non-stationarities will be transmitted to other macroeconomic variables, such as employment and output. Second, if shocks to energy variables result in persistence spreading to other macroeconomic variables, this raises serious questions about economic theories, such as real business cycle models, premised on output being stationary and has implications for the efficacy of Keynesian demand management policies. Third, whether energy variables contain a unit root has implications for forecasting energy demand and the correct modelling of energy and other variables, such as economic growth (for more details see Smyth, 2013).

Overview of existing studies

The early studies applied the Augmented Dickey-Fuller (ADF) unit root test to energy consumption for a large number of countries (Hasanov & Telatar, 2011; Narayan & Smyth, 2007). The main conclusion from these studies was that the unit root could be rejected for about one third of countries. While these findings serve as a benchmark, traditional unit root tests, such as the ADF test, have several limitations, meaning they have low power to reject the unit root null hypothesis. These limitations include low power to reject the unit root null hypothesis in the presence of one or more structural breaks, non-linearities in the data, if the alternatives are of a fractional form or if there is an insufficient number of observations. Each of these limitations have served as a catalyst for subsequent studies to re-examine whether there is a unit root using more
recent tests which address one or more of these shortcomings associated with traditional tests.

A limited number of studies have addressed the issue of the low power of traditional tests in the presence of non-linearities in energy variables (Hasanov & Telatar, 2011; Maslyuk & Smyth, 2009). Overall, the evidence from these studies is that energy variables contain a unit root (Aslan & Kum, 2011) or that the evidence is ambiguous (Aslan, 2011; Hasanov & Telatar, 2011).

A number of studies have addressed the issue of the low power of traditional tests to reject the unit root null hypothesis in the presence of one or more structural breaks. Most studies which have employed a univariate unit root test with one or two structural breaks have used the Lee and Strazicich (2003) Lagrange multiplier (LM) unit root test with one or two breaks (Agnolucci & Venn, 2011; Apergis & Payne, 2010; Aslan & Kum, 2011; Aslan, 2011; Lean & Smyth, 2013, 2014a, ; Maslyuk & Dharmaratna, 2013; Mishra & Smyth, 2014; Narayan et al., 2010). Some studies have employed the Narayan and Popp (2010) unit root test with one and two breaks (Apergis & Payne, 2010; Mishra & Smyth, 2014). The main finding from these studies is that energy consumption is stationary around a broken trend, although some studies have reached inconclusive results or found that energy variables contain a unit root, even after accommodating structural breaks (see eg. Aslan, 2011; Lean & Smyth, 2013; Maslyuk & Dharmaratna, 2013; Mishra & Smyth, 2014). Mishra and Smyth (2014) find that US monthly natural gas consumption contains a unit root with the Lee and Strazicich (2003) and Narayan and Popp (2010) unit root tests, but when the Narayan and Liu (2013) test, which accounts for both structural breaks and heteroskedasticity in high frequency data is used, the series is mean reverting.
There are also a growing number of studies that have tested for fractional integration in energy variables with and without structural breaks (Apergis & Tsoumas, 2011, 2012; Barros et al., 2011; 2012, 2013a; Gil Alana et al., 2010; Lean & Smyth, 2009). The most common finding from these studies is the degree of integration lies between 0.5 and 1, suggesting a high level of persistence with mean reversion taking a long time. The level of persistence is affected by the inclusion of structural breaks with more evidence of reversion in the presence of breaks.

A final set of studies have employed panel data to address the short span of data. One subset of studies have employed traditional panel unit root tests without structural breaks (Agnoluuci & Venn, 2011; Apergis et al., 2010; Hsu et al., 2008; Mishra et al., 2009; Narayan et al., 2008; Narayan & Smyth, 2007). Overall, these studies have found more evidence in favour of a panel unit root. A second subset of studies have employed panel tests that accommodate structural breaks to energy consumption or production. Among these, studies have applied the Im et al. (2005) and Westerlund (2005) panel unit root tests and the Carrion-i-Silvestre et al. (2005) panel stationarity test (Agnoluuci & Venn, 2011; Apergis et al., 2010, 2010a; Chen & Lee, 2007; Lean & Smyth, 2013, 2014a; Mishra et al., 2009; Narayan et al., 2008; Ozcan, 2013). Most of these studies conclude that energy consumption and production are stationary.

Many of the studies have applied unit root tests to aggregate data on energy consumption or production (Agnoluuci & Venn, 2011; Aslan & Kum, 2011; Chen & Lee, 2007; Hasanov & Teletar, 2011; Hsu et al., 2008; Mishra et al., 2009; Narayan et al., 2010; Narayan & Smyth, 2007; Ozcan, 2013; Ozturk & Aslan, 2011). The problem with doing this, however, is that focusing on aggregate energy variables
masks the fact that some types of energy might be stationary and others non-stationary. As a consequence, in the recent literature much attention has been given to examining the unit root properties of various types of disaggregated energy consumption and production. Some studies have considered various types of fossil fuels (Apergis & Payne, 2010; Apergis & Tsoumas, 2012; Aslan, 2011; Barros et al., 2011; Lean & Smyth, 2009; Maslyuk & Dharmaratna, 2013; Maslyuk & Smyth, 2009; Mishra & Smyth, 2014; Narayan et al., 2008;). Other studies have centred on renewable and alternative energy sources (Apergis & Tsoumas, 2011; Barros et al., 2012, 2013a; Lean & Smyth, 2013, 2014). There is no clear consensus in the literature on the unit root properties of disaggregated energy variables by energy type. The findings typically depend on the type of unit root test that is employed. A small number of studies have examined the unit root properties of (disaggregated) energy by sector (Apergis & Tsoumas, 2011; Aslan & Kum, 2011; Narayan et al., 2010). This is important because stationarity of energy variables might vary according to the sector in which they are involved. There are, however, not enough studies yet for a consensus to emerge on this issue.

*State-of-the-art*

We distinguish between univariate and panel data. With univariate data, the state-of-the-art is fractional integration tests, which accommodate seasonality (in high frequency data) and structural breaks, applied to disaggregated energy by type, preferably at the sector level (see eg Apergis & Tsoumas, 2012; Barros et al., 2013a). The fractional integration tests allow for differing degrees of persistence while employing disaggregated energy by type and sector allows for the fact different types of energy might exhibit different levels of persistence and different sectors depend differently on energy. With high frequency data, it is important to also account for
heteroskedasticity (Mishra & Smyth, 2014). The Narayan and Liu (2013) unit root test accommodates heteroskedasticity and structural breaks, but assumes a I(0)/I(1) dichotomy, which does not test for fractional integration. Moreover, the Narayan and Liu (2013) test requires seasonality to be first filtered out of the data. There are no unit root tests which simultaneously address fractional integration, structural breaks seasonality and heteroskedasticity in high frequency energy data. With panel data, the state-of-the-art are panel unit root and stationarity tests with structural breaks, again applied to disaggregated energy by type and sector. The literature has not generally applied panel fractional integration tests; an exception is Lean & Smyth (2009).

Recommendations for future research

Most studies are large multi-country studies. Of studies, which focus on a single country, most focus on various aspects of energy consumption or production in the United States. This is particularly so for extant studies of the integration properties of disaggregated energy by type. Thus, we know quite a lot about the unit root properties of various types of disaggregated energy consumption in the United States, but much less so for other countries. One suggestion for future research is to examine the unit root properties of disaggregated energy for countries other than the United States, along the lines of Lean and Smyth (2014a) for Malaysia.

A second feature of the existing literature is that most studies are at the national level. There are few studies which use data at the state level, restricted to Australia and the United States (Apergis et al., 2010, 2010a; Aslan, 2011; Narayan et al., 2010). Future research is needed to examine differences in the integration properties of (disaggregated) energy at the state level. There are advantages in exploiting sub-
national data; using sub-national data allows one to address potential heterogeneity in the behaviour of energy consumption across states (see Smyth, 2013).

Another direction for future research in this area is to apply unit root tests to examine convergence in energy consumption. Meng et al. (2013), who examine convergence in energy consumption per capita in OECD countries, is a first step in this direction. Future research could examine convergence in energy consumption at the sector level within specific countries, convergence of specific types of energy or convergence in energy consumption among countries at different levels of economic development.

Finally, there can potentially be more work on the efficiency of energy futures markets; for examples of this type of work, see Narayan et al. (2010) and Narayan et al. (2011). Recently, Narayan and Popp (2011) and Costantini et al. (2014) propose a seasonal unit root test that can be usefully applied to energy variables, particularly those that are sampled at the quarterly frequency. In this respect, seasonal unit root tests can be usefully employed to test for efficiency of energy futures.

3. Cointegration, Granger causality and long-run estimation

Motivation and implications
The literature on the relationship between energy and GDP, originating with Kraft and Kraft (1978), is motivated by the close perceived relationship between the two variables. Much of the literature has tested four competing hypotheses, which have important policy implications. These are (a) the conservation hypothesis – unidirectional Granger causality running from GDP to energy; (b) the growth hypothesis - unidirectional Granger causality running from energy to GDP; (c) the feedback hypothesis – bilateral Granger causality between energy and GDP; and (d) the neutrality hypothesis – energy and GDP are independent. The literature has
adopted progressively more advanced econometric methods. Mehrara (2007) identifies four generations of studies. Coers and Sanders (2013) suggest there is now a fifth generation of studies. There is, however, no consensus about the existence of a long-run relationship and direction of causality (Ozturk, 2010; Payne, 2010). This uncertainty has been a catalyst for further studies using even more recent methods.

As an extension of cointegration testing, studies have estimated the long-run elasticities. Typically, such studies have examined the long-run effect (elasticity) of income with respect to energy indicators and the long-run energy elasticity with respect to income; see Narayan et al. (2010) and the references therein.

**Overview of existing studies**

Much of the early literature examined the causal relationship between energy and GDP within a bivariate framework. The problem with this approach is that omitted variables can lead to the wrong conclusions about causal inference (Lutkepohl, 1982). Consequently, the subsequent literature has examined the causal relationship between energy and GDP within a multivariate setting, adding one or more variables in addition to energy and GDP. Apergis and Tang (2013) find that models with three or more variables are more likely to support the growth hypothesis than studies employing a bivariate model. The problem with just adding random third or fourth variables, however, is that the choice of additional variables is *ad hoc* without any underpinning theoretical framework. Stern (1993, 2000) was the first to highlight the potential complementarities between energy and other inputs (capital and labor) in the production process. The use of an augmented production function framework in which GDP is treated as a function of capital, labour and energy consumption has become the norm in the literature. An alternative to including labor in the production
function is to normalize the production function by labor/population and specify it in per capita terms (see eg. Lee et al., 2008; Liddle, 2013; Narayan & Smyth, 2008).

In addition to examining the relationship between energy and GDP, many studies examine the relationship between energy, GDP and a third and, sometimes, a fourth variable. Most of these studies now employ an augmented production function model in which, in addition to capital, labor and energy, the third (or fourth) variable is included on the right-hand side. One set of studies examines the relationship between energy, urbanization and GDP (see eg. Liddle, 2013; Liu & Xie, 2013; Mishra et al, 2009a; Sadorsky, 2013; Wang, 2014). A second set of studies examines the relationship between energy, financial development and GDP (see eg. Coban & Topcu 2013; Jalil & Feridun 2011; Shahbaz & Lean, 2012; Sadorsky, 2010, 2011).

A third set of studies examine the relationship between energy, GDP and trade (see eg. Aissa et al., 2014; Farhani et al., 2014; Lean & Smyth 2010; Narayan & Smyth, 2009; Nasreen & Anwar, 2014; Sadorsky, 2011a, 2012;). Shahbaz et al (2013) examines the relationship between energy consumption, financial development, GDP and trade in China within the one empirical framework. Traditionally, electricity has been classified as a non-traded good, produced and consumed within the country of origin. It is only recently that electricity has been traded between countries (Srinivasan, 2013). Lean and Smyth (2014c) extend the third group of studies to examine the contribution of Bhutanese hydroelectricity exports to India on economic growth in Bhutan within a production function framework. Bhutan is an interesting country to examine the effect of exports of electricity on GDP because Bhutan not only trades electricity with India, but electricity represents Bhutan’s major export. Other studies extend the modelling framework in other directions, such as the
relationship between energy consumption, GDP and foreign direct investment (see eg. Omri & Kahouli 2014), and energy consumption, political instability and tourism (Tang & Abosedra 2014).

In terms of single country versus panel studies, there are a multitude of single country studies (see Apergis & Payne, 2011, Table 1; Ozturk, 2010; Payne, 2010). Many of these studies have been plagued by only having relatively short time-series. A common approach to address the short time-series has been to employ the autoregressive distributed lag (ARDL) bounds test approach suggested by Pesaran et al. (2001) with the small sample critical values tabulated in Narayan (2005) (see eg. Baranzini et al., 2013; Chandran et al., 2010; Fuinhas & Marques, 2012; Odhiambo, 2010; Sari et al., 2008; Shahbaz et al., 2012a; Wolde-Rufael, 2010; Tang, 2008). The results from studies for individual countries, however, have been divergent.

These differences reflect, inter alia, differences in econometric approaches, institutional characteristics in specific countries, model specification, variable selection and time period (Apergis & Payne, 2011; Apergis & Tang, 2013; Ozturk, 2010; Payne, 2010). Stern and Enflo (2013) note that relatively small samples produce sampling variability. To address this issue, Stern and Enflo (2013) and Vaona (2012) use a long time-series (around 150 years) for Sweden and Italy, respectively, and find that the relationship between energy and GDP has changed over time.

For most countries, a very long time-series is not available. Thus, an alternative way to address the short time-series for individual countries has been to employ panel data models. Mehrara’s ‘fourth generation’ models, published from around 2003 onwards, analysed the energy GDP relationship using (bivariate) panel cointegration and panel.
error correction models (see eg. Lee, 2005; Soytas & Sari, 2003, 2006). Coers and Sanders (2013) so-called ‘fifth generation’ models, published from 2007-2008 onwards, use panel VECM models, which also control for capital-energy complementarities and estimate elasticities via methods, such as panel fully modified OLS (FMOLS) and panel dynamic OLS (DOLS) (see eg. Apergis & Payne, 2009, 2009a, 2010a, 2011; Coers & Sanders, 2013; Lee & Chang, 2008; Lee et al., 2008; Liddle, 2012, 2013; Narayan & Smyth, 2008; Sadorsky, 2011a, 2012). This literature attempts to address structural breaks in the cointegrating vector (see eg. Narayan & Smyth, 2008) and cross-sectional dependence in the cointegration test (see eg. Liddle, 2013). The long-run energy elasticity has generally been in the range 0.1 to 0.4.

A limitation with using aggregate energy data to examine the energy-GDP nexus is that aggregate energy does not reflect the extent to which different countries rely on different energy resources (Yang, 2000). Thus, finding, or failing to find, a relationship between aggregated energy consumption and economic growth, might mask nuanced relationships between specific energy types and economic growth. Beginning with Yang (2000) there are few studies that consider the relationship between energy consumption, disaggregated by type, and economic growth (Alkhathlan & Javid, 2013; Bowden & Payne 2009; Ewing et al, 2007; Hu & Lin, 2008; Payne, 2009; Sari & Soytas, 2004; Sari et al, 2008; Tsani, 2010; Wolde-Rufael, 2004; Yang, 2000; Yuan et al, 2008; Ziramba, 2009). A few studies have applied an augmented production function to analyze the relationship between nuclear or renewable energy consumption and energy growth (see eg. Aissa et al. 2014; Apergis & Payne 2010b, 2010c, 2011a, 2012; Chu & Chang, 2012; Ohler & Fetters, 2014; Pao & Fu, 2013; Wolde-Rufael & Menyah, 2010). Other studies have focused on the relationship between specific fossil fuels, such as natural gas (Farhani et al., 2014)
and oil (Chu & Chang, 2012) and GDP. There is a large subset of the literature examining the relationship between electricity consumption and GDP (see Payne 2010 for a review).

There are also a few studies which have compared the relationship between both aggregate and disaggregate energy consumption and economic growth in alternative specifications (Alkhathlan & Javid, 2013; Wolde-Rufael, 2004; Yang, 2000; Yuan et al., 2008; Zhang & Yang, 2013). Other papers look at the relationship between disaggregated energy consumption and alternatives to GDP, such as industrial production (Sari et al. 2008). There are, however, very few studies which have examined the relationship between economic growth and disaggregated data on various energy types, using an augmented production function model approach (see e.g. Liddle, 2013; Pao & Fu, 2013; Soytas & Sari, 2007). There is no clear consensus at this point about the manner in which elasticities for specific types of energy differ, particularly allowing for energy-capital complementarities. One problem is the results might be confounded because specific energy types might not be sufficiently independent of total energy (Bruns & Gross, 2013).

In terms of geographic focus, the majority of studies have focused on developed and industrialized countries, reflecting the availability of reliable data (Payne, 2010). Apergis and Tang (2013) find that support for the competing hypotheses concerning Granger causality is linked to the level of economic development with more support for the growth hypothesis at higher levels of economic development. Most single country studies have employed data at the national level, although there are a limited number of studies which have employed sub-national data, particularly for China (see e.g. Akkemik et al., 2012; Herrerias et al, 2013; Zhang & Xu, 2012). The results are
not universal, but provide more support for the conservation hypothesis in China, particularly in the industrialized coastal seaboard provinces. Overall, the findings for China at least, suggest that taking a regional perspective is useful.

State-of-the-art

Several conclusions emerge regarding the current state-of-the-art with respect to examining the energy-GDP relationship. First, models should be multivariate to avoid omitted variables bias and should preferably employ an augmented production function that accommodates complementarities between energy and other inputs. However, in circumstances in which only a short span of data is available and, for the purposes of drawing policy implications, the focus has to be on individual countries, there is a trade-off. The trade-off is between employing a bivariate framework, which potentially results in omitted variable bias, and a multivariate model, which potentially results in over-parameterising the model and loss of degrees of freedom.

Second, unless it is necessary to use data for individual countries to derive policy conclusions for those countries, models should employ panel data to improve the power of unit root and cointegration tests. Third, when using data for single countries, a long time span is preferable. Stern and Enflo (2013) and Vaona (2012) set the gold standard in this regard, although in most cases 150 years of data will not be available.

Fourth, rather than just presenting the Granger causality results, the magnitude, sign and significance of the long-run elasticities should be calculated. Fifth, energy data should be disaggregated by type and preferably sector to account for differences in energy intensity. Studies should compare the results for aggregated and disaggregated

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1 In recent reviews, Payne (2010) and Liddle (2012) outline several points of consensus regarding state-of-the-art and this section borrows several points from their reviews.
energy consumption data. Sixth, energy consumption data should be adjusted for the quality of the energy source (Liddle, 2012; Stern, 1993, 2000). Seventh, the GDP data should be adjusted to accommodate the unrecorded economy (Ozturk, 2010). Eighth, attention should be paid to identifying how results differ according to level of economic development. For multi-country results, Apergis and Tang (2013) use a logistic modelling approach, which presents a path forward in this respect.

Recommendations for future research

There are, we believe, three directions for future work with respect to cointegration, Granger causality, and long-run estimates of the effect of non-energy variables (say GDP) on energy variables or vice versa. First, not much is known about whether cointegration between energy and non-energy variables is regime-dependent. In other words, is cointegration restricted to certain phases of the economic cycle? Similarly, if cointegration is indeed found to be regime-dependent, the question becomes whether the long-run effects and indeed Granger causality are also regime-dependent. This modelling approach also leaves open the prospect that there may well be certain regimes in which the relationship (either in terms of cointegration, Granger causality or long-run effects) may be stronger than in other regimes. This finding can have implications for energy policy and planning. As much as this question is interesting, it will require time-series data that is much longer than what much of the literature has considered. This is the challenge, but it is one that should be taken.

Second, there is limited knowledge of whether cointegration, Granger causality, and long-run estimates are time-varying. Time-varying cointegration, Granger causality, and long-run estimation models should be considered. Third, there is limited research on whether energy variables can forecast non-energy variables (see Narayan et al.,
2014) and whether energy variables themselves can be forecasted (Hayat and Narayan, 2010). On forecasting, recent developments are in applications of both time-series data (Westerlund and Narayan, 2012, 2014a, Makin et al., 2014; Narayan et al., 2014a, b) and panel data (Westerlund and Narayan, 2014; Narayan et al., 2013).

4. Conclusions

The goal of this paper was to review the literature on two popular strands of literature in energy economics; namely, unit root testing and cointegration, Granger causality, and long-run estimation—that have been motivated by recent developments in applied econometrics. This is important because despite what seems to be consensus on findings from these two strands of the literature, more applied papers continue to be archived. The question is what additional things do we learn from these additional applications? We review this literature and discuss a range of new directions for research. We find that both literatures have more or less reached consensus. The unit root literature, for example, has concluded that when the state-of-art econometric techniques are used energy variables are stationary. Similarly, the cointegration literature almost always finds that energy variables share a long-run relationship with non-energy variables. This, therefore, seems to suggest that the evidence that there is cointegration is a stylised fact of the literature. The same, however, cannot be claimed with respect to the evidence on Granger causality, for which findings are mixed. These mixed findings reflect differences in econometric approaches and model specification, among other things. One particular issue is the trade-off between omitted variable bias and over parameterisation in bivariate and multivariate frameworks respectively with short spans of data. While a panel data model seems to offer a solution to biases resulting from omitted variable(s) and over-parameterisation,
the cost is high when the focus of research is on a single country, as opposed to a group of countries. We do not take a particular stand on this, leaving to applied researchers the decision to choose the model, conditional on the research question.
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