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Price discovery analysis of green equity indices using robust asymmetric vector autoregression

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A B S T R A C T

Covering the first commitment period of the Kyoto Protocol (2008–2012), we perform a price discovery analysis to determine Granger causality relationships for a range of prominent green equity indices with the broader equity and commodity markets. Three pivotal contributions are made. Firstly, an expanded database is used that gives greater depth to the price discovery analysis relative to previous literature. Prominent global, regional and sectoral green equity indices are considered, as well as a broader set of commodities including crude oil, natural gas and emissions. The inclusion of natural gas recognises its role as the transition fossil fuel to a low carbon economy. In addition to the main European Union Allowance traded under the EU Emissions Trading Scheme, Certified Emissions Reduction (CER) prices are also included in the emissions database to capture activities under the global Clean Development Mechanism. Secondly, a problem with conventional symmetric vector autoregression is that its implementation commonly leads to large occurrences of insignificant parameters. Therefore, as a first layer of robustness, we utilise an asymmetric vector autoregression model to perform the Granger causality testing, which addresses this limitation by means of allowing different lag specifications among the system variables. Thirdly, explicit recognition is made in our study of the *multiple comparisons bias* inherent in our high-dimensional testing framework, which is the non-negligible likelihood of identifying statistically significant results by pure chance alone. As a second layer of robustness, we utilise a *generalised* Holm correction method to control this source of bias. At conventional statistical significance levels, we find that the FTSE 100 and FTSE Global Small Cap equity indices have a causal effect on all of the green equity indices, with limited evidence of causality in the opposite direction. Within the green equity markets, we find evidence that the chosen sectoral index has a Granger causal effect on one of the two global indices considered and also the regional index. This price transmission provides modest evidence that the global green economy is becoming ever more integrated. NBP gas is shown to have a causal effect on all of the green equity indices, whereas we find no such evidence for Brent oil. The former observation may reflect the increasing role of gas as the transition fuel to a low carbon economy, playing a key role in decisions on power generation mix and associated capital investment. Finally, we find no evidence that EUA or CER prices have a causal effect on green stocks, consistent with previous findings and likely reflecting the excessively low prices being commanded for compliance permits in the European emissions markets.

1. Introduction

The 2013 report of the Frankfurt School-United Nations Environment Programme Collaborating Centre for Climate and Sustainable Energy Finance (herein referred to as the FS-UNEP, 2013 report) on global trends in renewable energy investment describes 2012 as a particularly challenging year. Overall new investment in renewable energy in 2012 was down 12% on 2011 levels to $244bn, after an almost sustained period of double digit growth since 2004 (with 2009 being the only exception to this). The public markets saw the most dramatic levels of relative decline. Investment fell approximately 61%, from $10.6bn in 2011 to $4.1bn in 2012. Of the two primary renewable energy types, i.e. wind and solar, new public market investment fell 72% and 50% respectively. The absolute levels of public market investment have consistently been dwarfed by the level of asset finance investment for the utility-scale roll out of renewable energy, which in 2012 was $149bn; 36 times that of the public market investment. This highlights the major challenge in attracting private institutional finance to renewable energy and clean technology companies. Indeed, the green equity sector has substantially underperformed the broader equity markets over recent years. Given this difference in equity market performance, we conduct a price discovery analysis to determine what interactions exist both within the green equity sector and between

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this sector and the broader equity and commodity markets, where in the latter we include oil, natural gas and emissions.

The two prominent studies in this space are Henriques and Sadorsky (2008) and Kumar, Managi, and Matsuda (2012). The focus of these studies has predominately been on the relationship between the stock prices of clean energy companies and oil or technology companies. Henriques and Sadorsky (2008), using Wilder Hill Clean Energy Index data and a vector autoregression model, studied the dynamic relationship between the stock prices of alternative energy companies, oil prices, interest rates and the Arca Tech 100 index of technology companies. Interestingly the authors find that shocks to technology company stock prices have a larger impact on the stock prices of alternative energy companies than oil prices. They noted that the success of alternative energy companies often depends upon the success or failure of specific technologies; therefore, they have more in common with technology companies than fossil fuel based energy companies. This relationship with technology firms was also found by Kumar et al. (2012) who expanded on the literature in considering carbon prices in addition to oil and technology stocks. Kumar et al. (2012) include three indexes in their research: the Wilder Hill New Energy Global Innovation Index; the Wilder Hill Clean Energy Index; and the S&P Global Clean Energy Index. The authors confirm that clean energy stock prices are influenced by oil prices, interest rates and technology stock prices but perhaps surprisingly not by the prices of carbon allowances. Other related literature includes Boulatoff and Boyer (2009), Sadorsky (2011), Sabbaghi (2011) and Bohl, Kauffmann, and Stephan (2013).

As a first contribution, we use an expanded database of green equity indices, broader equity market indices and commodities for the price discovery analysis in our study, which offers notable benefits. Specifically, the suite of green equity indices extends previous literature by including global, sectoral and regional indices. As set out above, Henriques and Sadorsky (2008) consider one global index in their study and Kumar et al. (2012) consider three specific global indices. Our study extends this literature in considering two prominent global indices, one regional index and one sectoral index. The indices are drawn from the following index series: Bloomberg New Energy Finance Clean Energy Indices; FTSE Environmental Markets Indices; and Wilderhill Indices. This extended database allows for greater depth in determining general global, regional and sectoral price transmission. The commodities database also extends previous literature by means of considering natural gas market information, where previously only oil has been considered. The motivation for the inclusion of natural gas is centred on the recognition that natural gas is seen as the transition fossil fuel to a low carbon economy. The emissions market data in our study additionally extends on previous literature by means of considering Certified Emissions Reduction (CER) prices, along with the prices of the primary compliance unit of the European Union Allowance (EUA) within the EU Emissions Trading Scheme. CERs are awarded against projects funded and developed under the global Clean Development Mechanism (CDM) as set out under the Kyoto protocol. As the CDM encourages private investment from developed nations into renewable energy and clean technology projects in developing nations, the CER prices are included here as a measure of this activity as it would be reasonably expected that some of the constituent companies within the green equity indices considered in our study would be involved in the CDM markets.

As a second contribution, the methodology employed in our analysis extends previous literature, which has applied the conventional vector autoregression (VAR) model to perform its analysis (Henriques & Sadorsky, 2008; Kumar et al., 2012). A limitation of VAR is that the symmetrical nature of the model specification is such that its implementation often leads to the estimation of a large number of insignificant coefficients (Keating, 2000). Much of the literature that implements VAR models overlooks this issue, although it has been recognised as a problem since the seminal work of Sims (1980). Hsiao (1981) and Litterman (1986) propose Bayesian approaches that seek to constrain the VAR coefficients in an effort to achieve more efficient estimates (Keating, 2000). In contrast to these approaches, Keating (2000) proposes a flexible methodology, which allows for asymmetry in the specification of the vector autoregression model. Within an asymmetric vector autoregression (AVAR), each equation of the model system contains the same variables, ensuring that parameter estimates are both consistent and efficient, but the difference over conventional symmetric VAR models is that the lags of the variables are allowed to potentially differ. Keating (2000) notes that parameter estimates from AVAR models generally have smaller standard errors. Furthermore, it is noted by Keating (2000) that point estimates within an AVAR model selected with the Akaike information criterion are generally of comparable size to those obtained from VAR. Given that VAR is nested within the broader AVAR specification, AVAR offers a flexible method to address the issue of obtaining large numbers of insignificant coefficients. We therefore employ the AVAR model as a first layer of robustness to examine Granger causality between the variables of interest in our study.

As a third contribution, we explicitly recognise that in analysing the expanded database using AVAR, a multiplicity of testing is performed that introduces *multiple comparisons bias*, which we control using a generalised Holm correction method (Romano, Shaikh, & Wolf, 2010). The bias arises when performing multiple hypothesis tests simultaneously, which leads to the non-negligible likelihood of identifying statistically significant results by pure chance alone, rather than on the basis of true statistical relationships. Without controlling for multiple comparisons bias, the probability of rejecting true hypotheses, i.e. making erroneous *false discoveries*, is increased. Addressing the bias is important as it calls into question, and potentially undermines, findings and conclusions presented at the conventional significance levels (i.e. 1%, 5% and 10%). To highlight the issue, results are first considered at the conventional significance levels and then the analysis is revisited with the generalised Holm correction. The analysis is in the spirit of Cummins (2013a,b).

The remainder of the paper is organised as follows. Section 2 describes the dataset used in the study and in particular the range of green equity indices considered. Section 3 presents the main findings of the price discovery analysis, reporting the Granger causal relationships between markets. The exact specification of the AVAR model is described in this section. Section 4 sets out the scale of the multiple comparisons problem inherent in the testing, while revisiting the empirical results in light of this. Section 5 concludes.

2. Data description

For the price discovery analysis presented later, daily prices over the period 2 June 2008–1 May 2013 are used. The data is grouped into three categories: green equity indices, mainstream equity market indices and commodity markets. The green indices span global, regional and sectoral classifications and so permit a more in-depth price discovery analysis relative to previous literature. The green equity indices are drawn from the following prominent index series: Bloomberg New Energy Finance Clean Energy Indices; FTSE Environmental Markets Indices; and Wilderhill Indices. The global indices considered include the Wilderhill New Energy Global Innovation (NEX) index and the FTSE Environmental Opportunities Renewable and Alternative Energy index. The NEX is comprised of companies worldwide whose innovative technologies and services focus on generation and use of cleaner energy, conservation and efficiency, and advancing renewable energy generally. Included are companies whose lower-carbon approaches are relevant to climate change, and whose technologies help reduce emissions relative to traditional fossil fuel use. The FTSE EO Renewable and Alternative Energy index comprises all the companies in the Renewable and Alternative Energy subcategory of the FTSE Environmental Opportunities all-share index that meet the defined criteria for inclusion in this subcategory. In terms of regional indices, we focus on the Bloomberg Europe, Middle East & Africa Clean Energy index, which tracks clean energy companies domiciled in Europe, the Middle East and Africa. As we are particularly interested in examining relationships with the emissions markets and