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Dependence changes between the carbon price and its fundamentals: A quantile regression approach

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HIGHLIGHTS

- Quantile-based dependence relationships in EUA futures market are discussed.
- Dependence of EUA-energy and EUA-macro economy vary from one phase to another.
- We found three significant structural breaks during the whole period.
- Dependence changes of EUA-energy and macro economy across the breaks are analyzed.
- Five influence paths from determinants to carbon future price are proposed.

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ABSTRACT

This paper focuses on the quantile-based dependence and influence path between European Union allowance (EUA) and its drivers (energy prices and macroeconomic risk factors) during the three phases of the European Union Emissions Trading Scheme (EU ETS). Meanwhile, the quantile-based dependence changes sourced from exogenous shocks are explored as well. Our empirical evidences suggest that: (i) the reaction of fluctuation in carbon price in relation to its drivers across its conditional distribution in different phases is highly heterogeneous; (ii) production restrain effect → aggregated demand effect → substitution effect, the evolution pattern of influence paths from Phase I to Phase III exists in the prices of both coal and gas, whereas, the evolution pattern of oil price is substitution effect → production restrain effect → production restrain effect; (iii) for the macroeconomic risk factors, differing with the nearly stable energy price path in Phase I, the unstable industrial production paths are explored during Phase II and Phase III; (iv) the significant dependence changes caused by three structural breaks are confirmed during the whole period, and both effects from the occurrence of financial and energy shortage risks generate unstable dependence changes to commodity price index, coal and gas prices, but a stable dependence change to oil prices. However, the stable dependence changes to stock price index and T-bill rate are mainly affected from the occurrence of financial risk; (v) the market risk of carbon market measured by Value at Risk is mainly affected by energy prices, but commodity price index and the T-bill rate also have significant effects on it after the impact of financial risk.

1. Introduction

The European Union Emissions Trading Scheme (EU ETS), the first and largest cap-and-trade carbon trading scheme in the world, has been regarded as the "flagship" policy by the European Commission (EC) for implementation of the emission reduction targets set by the Kyoto protocol[1] since it's official establishment in 2005. Correspondingly, the carbon market with a rapid development and steady expansion in size, liquidity, trading volume and complexity has shown increasingly close interaction with energy and financial markets. Therefore, the obvious financial attributes of carbon market have spurred considerable interest of scholars, regulators, investors and risk managers, and have instigated researchers to conduct a large number of researches on the pricing mechanisms in carbon market.

One strand of studies had gone a bit far in modeling the price dynamics of carbon price on a daily or intraday basis (see, for example [1–7]), EUAs volatility dynamics and forecasting (see [8–21]) and the market efficiency (see [22–24]) and risk

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[1] The Kyoto Protocol, an international legally binding agreement linked to the United Nations Framework Convention on Climate Change, was officially approved and came into force on February 16, 2005 to reduce greenhouse gas (GHG) emissions.

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management (see [25–27]). Another strand of literature focused on the potential drivers of carbon price and had underlined the complexity of the carbon market pricing mechanism (see among others the early work by Alberola et al. [28], Chevallier [29], Hintermann [30], Keppler and Mansanet-Bataller [31], Kim and Koo [32], Declercq et al. [33], recent contributions by Creti et al. [34]; Lutz et al. [35], Aatola et al. [36], Bertrand [37], Koch et al. [38], Hammoudeh et al. [39], Yu and Mallory [40], Bergh et al. [41], Boersen and Scholtens [42], Cansino et al. [43]). Overall, the carbon price is mainly driven by the balance between the supply and demand of the EUA (European Union Allowance). On the supply side, the quantity of allowances is determined by the institutional policies of the EC. The demand for allowance is closely linked to energy prices, extreme weather conditions, economic growth, macroeconomic risk factors, wind and solar electricity production and issued Certified Emission Reductions (CERs).

In addition, the existing literature also considered the cross-linkages mechanism between carbon, other energy and financial markets. In particular, spillover effects between carbon market and other energy markets are addressed by many scholars. For example, Reboredo proposed a multivariate conditional autoregressive range model with bivariate lognormal distribution to capture the volatility spillovers between oil and EUA markets during the second phase of EU ETS, and the results indicated the volatility dynamics and leverage effects on Brent oil and carbon price volatility and no significant spillovers between the two markets [44]. Similarly, Yu et al. [45] also focused on the linkage between the carbon and crude oil market. However, the difference was that of considering the inner factors on different timescales and the non-linear relation between carbon and crude oil market, Yu et al. [45] explored the linear and non-linear Granger Causality between carbon and crude oil prices in a multi-scale analysis framework.

More recently, Zhang and Sun [46] applied DCC-TGARCH model and full BEKK-GARCH model to investigate the volatility spillover between EUA futures price and fossil energy prices, and found out that coal market had the highest positive correlation with carbon market, followed by natural gas and Brent oil markets, but there was no significant volatility spillover between carbon and Brent crude oil market. Additionally, Balcilar et al. [47] explored the volatility spillovers between energy futures prices and EUA future prices by a MS-DCC-GARCH model, and provided hedging strategies for carbon risk management. Differing from the literature mentioned above, based on high-frequency data, Rittler [48] investigated the volatility spillovers from the EUA futures to the EUA spot market using the Granger-causality tests and the UECCC-GARCH model, and revealed the spillovers from the futures to the spot market. Besides, considering the importance of the interactions between the carbon price and other fundamental drivers, Chevallier [49] specified and estimated several Markov-switching VAR models to interlink carbon price, energy and macroeconomic variables, and confirmed the existence of a link between the macroeconomic factors and carbon price, but the carbon-macroeconomic relationship might be weakened for some periods. Moreover, the interactions between the EUA and CER markets were also identified [50–53].

As the literature mentioned above, carbon prices had been demonstrated to be closely associated with energy prices and macroeconomic activity at the theoretical and empirical level (see Kanen [54]; Chevallier [29]; Chevallier [49]; Reboredo [55]; Yu et al. [45]). However, there is scant literature on the dependence dynamics of EUA-energy and EUA-macro economy during the whole three phases of EU ETS. Only Reboredo [55] revealed the average and tail dependences between EUA and crude oil market by copulas, and mentioned the implications of EUA-oil market for portfolio management. More importantly, both the dependence dynamics of EUA-energy and EUA-macro economy may change in response to the different economic conditions in each phase of EU ETS, the possible effects of structural breaks caused by the onsets of financial crisis or market turmoil must be considered.

To fill this knowledge gap, the main objectives of our research, therefore, are to focus on the influence paths and dependence dynamics, notably, the tail dependence between EUA and its fundamentals drivers. Initially, we will examine the quantile-based dependence dynamics of EUA-energy and EUA-macro economy, and analyze the influence paths from energy and financial markets to carbon markets in different phase of EU ETS. Then, considering that the structural breaks may not relate to the division of compliance phases in EU ETS, we will explore the possible structural breaks during the whole period of EU ETS. Finally, we will investigate the changes in dependence and influence paths after analyzing the effects of every structural break using a quantile regression, a methodology, less sensitive to outliers and adopted widely to explore the relationship between financial variables, which allows greater flexibility in the normal distribution hypothesis of error term than the ordinary least squares regression (OLS), and more interestingly, can capture the information on the average as well as the lower and upper tail dependence [56–59].

Generally, by specifying and estimating several quantile regression models to interlink the carbon price, energy and macroeconomic risk factors, our study makes four major contributions to the existing literature. First, our paper puts forward the theoretical concepts about three influence paths from energy markets to carbon market, and two influence paths from financial markets to carbon market, respectively. Second, when comparing with the existing literature, we aim at modeling the average and tail dependences between the carbon and energy prices during the three phases of EU ETS, but also taking into account the effects of macroeconomic risk factors which had been highlighted in previous studies. Later on, we compare and analyze the dependence dynamics and influence paths during different phases. Third, we are well aware of the fact that the dependence may be changed due to impact from the demand and supply sides of carbon allowances, therefore, we provide empirical evidence of possible structural breaks during the whole period, and explore the changes in dependence and influence paths. Fourth, by estimating the quantiles of carbon price at 0.01 level that is equal to the risk value at 99% confidence level, we throw some lights on the effects of energy prices and macroeconomic risk factors on the market risk of carbon price, which is beneficial to the management of carbon market risk.

The remainder of the paper is organized as follows. Section 2 describes a brief theoretical frame of the transmission paths among the carbon markets, energy markets, and financial markets, and defines the concepts of three influence paths of EUA-energy, and two influence paths of EUA-macro economy, respectively. Section 3 details the data and methodology used. Section 4 displays the results of quantile regression, including the comparisons of dependence dynamics and influence paths of EUA-energy and EUA-macro economy during the three phases of EU ETS, likewise, the changes in dependence and influence paths caused by every structural break are addressed as well. Section 5 contains brief conclusions and policy implications. The framework of this paper is presented by Fig. 1.

2. Theoretical model

With the rapid development of the carbon markets and the growing integration trend of energy finance, the obvious dependence among the carbon, energy, and financial markets is important for market participants to manage the fluctuation risk of