Online-Appendix zu

„ Carbon Pricing: A Comparison between Germany and the United Kingdom “

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8 Summary and Conclusions

This paper analyzed two research questions. First, the impact of carbon pricing on tackling CO_2 emissions in Germany and the United Kingdom. Second, whether the Market Stability Reserve introduced in 2019 acted as a Carbon Price Floor (CPF) for Germany.

By using an Ordinary Least Squares (OLS) model for panel data, it was determined that the United Kingdom was more effective in combating CO_2 emissions due to its CPF policy. This result supports existing evidence of Gugler et al. (2021), who established that the carbon policy of the UK was more effective in reducing CO_2 emissions than the subsidies that Germany gave to boost renewable technologies. Moreover, authors (see Marion (2019); Abrell et al. (2021)), who studied the impact of the CPF in the UK, determined that the policy was effective in reducing CO_2 emissions. Other authors (see Edenhofer et al. (2017); Gerlagh et al. (2020)), who studied the EU ETS in Europe, resolved that a CPF would improve the effectiveness of the EU ETS.

To test the second hypothesis, a model of Differences in Differences (DD) for panel data was employed. The model determined that the MSR reduced the CO_2 emissions of both countries. However, its impact increased significantly in Germany, enabling its comparison with the CPF of the UK. This result endorsed the findings of Gugler et al. (2021), who determined that when the British carbon price was above 38 €/tCO_2, its marginal benefit started to decline. The British carbon price exceeded these levels during 2019 and 2020 when the MSR was in operation. Thus, the MSR was significantly more effective in tackling the CO_2 emissions of Germany.

Previous research has mainly focused on evaluating the impact of carbon pricing in CO_2 emissions (see Gerlagh et al. (2020); Gugler et al. (2021); Abrell et al. (2021)) but has excluded one of these two factors: the influence of nuclear energy, and the impact of the MSR in the EU Emissions Trading Scheme (EU ETS). Both factors are considered in this research because nuclear energy is a carbon-free source and the MSR acted as a market stabilizer. Accordingly, the results of this study demonstrate that both factors are relevant for the analysis.

Nuclear energy proved to be a relevant factor of the CO_2 emissions across countries and fossil fuels. In the UK, nuclear has a negative relationship with CO_2 emissions of both coal and gas. It means that nuclear acted as a substitute for fossil fuels. Since the British Government supports nuclear energy, the finding makes sense. Inversely, in Germany, nuclear energy has a positive link with CO_2 emissions of all fossil fuels. It denotes that when Germany produced nuclear energy, it also increased its production from coal and gas by a factor of 0.7, approximately. The link with lignite was stronger, of 1.3x. In summary, nuclear acted as a complementary for fossil fuels. Since Germany has reduced its nuclear generation due to the phase-out in 2022, both fossil fuels and nuclear may have been necessary to fulfill its electricity demand at the same time. Consequently, the link that each country has between nuclear energy and CO_2 emissions corresponds to their opposing views on nuclear.

Since the introduction of the EU ETS in 2005, the EU Commission has taken feedback and has actively improved its policy. The MSR established in 2019 was one of the improvements. The MSR controls the supply of European Allowances (EUAs) and avoided a price crash during the Covid-19 crisis. Despite the MSR was active for both countries, this paper has proved that it affected mostly German's CO_2 emissions. The DD model resolved that the MSR accounted for a daily reduction of Germany's CO_2 emissions by 39.5 tonnes in comparison with the UK. Currently, the discussion of whether the creation of a CPF for the EU ETS is open (see Gerlagh et al. (2020)). Annalena Baerbock, the leader of the German Green Party, announced that, if elected, her party will raise the carbon price to 60 €/ton by 2023 (NTV, 2021). The finding that the MSR may have acted as a CPF for Germany, adds value to the existing literature and debate.

However, the promotion of renewable energies is the final goal of carbon pricing. Therefore, this paper has included the electricity generation of solar and wind energy in the analysis. The finding is that electricity generation from renewables has reduced CO_2 emissions across countries and fossil fuels. For Germany, solar energy and wind onshore have displaced the highest share of coal and gas. Lignite has been significantly affected only by wind onshore. For the UK, both wind onshore and offshore were the most significant sources. The results go in line with each country's development. Germany ranked 4th in the world for its photovoltaic installed capacity (Clean Energy Wire, 2020). While the UK has the largest capacity of offshore wind in the world (Renewable UK, 2021).

Given the results of this paper and prior findings, it is clear that carbon pricing has reduced CO_2 emissions and has promoted the development of renewable energies. Also, these findings demonstrate that the reforms taken by the EU Commission to consolidate the EU ETS are effective, too. Still, it is important to mention that in February 2018, the EU Commission approved a reform of the EU ETS for phase 4 (2021 – 2030). The period analyzed in this paper excludes the latest reform. Beck and Kruse-Andersen (2018) run simulations until 2125 to estimate the effects of this reform. They concluded that the new MSR was more effective in the short and long run. The authors stated that the new MSR was being affected by the market demand on EUAs, and thus it was not being set by the EU Commission. The new MSR gives space for further research.

There are some limitations to this research. First, the focus of the research is on analyzing the impact of carbon pricing on CO_2 emissions. Investments in renewables and energy efficiency improvements are excluded. The inclusion of electricity load relates partially to energy efficiency, but it is not the same. Second, electricity imports are excluded from the analysis. Marion (2019) points out that it is unlikely that the UK has increased its electricity imports because the UK is not well interconnected. The same cannot be said about Germany.

This study opens two discussion points in carbon pricing. First, the effectiveness of the MSR as a market stabilizer, and therefore as a CPF for Germany. Even though the global economy has not recovered from the Covid-19 crisis, the EU ETS price has kept its uptrend in 2021. From 4th January to 11th August, the EU ETS price has increased from 33.7 €/ton to 57.8 €/ton (Ember Climate, 2021). The latest reform mentioned in the previous paragraph may have improved the effectiveness of the EU ETS. Second, the consideration of national energy policies when two countries are compared. The inclusion of nuclear energy in the model allows us to see that the effectiveness of the UK CPF, when compared to Germany, is positively biased by its nuclear policy.

Despite 191 parties (including the EU) signed the 2015 Paris Agreement, the EU and the UK are pioneers in implementing a carbon market (The United Nations, 2021). These complementary schemes have been analyzed in this study and the results lead to two recommendations for countries that are adopting an ETS (i.e. South Korea and China). First, that the MSR could be as effective as a CPF. Second, to assess their individual country policies (i.e. nuclear policy) when designing an ETS.

A Appendix

Dynamic Conditional Correlation Multivariate Generalized Autoregressive Conditional Heteroskedasticity Model

There is another model that could have served to test the two hypotheses of this thesis. Unfortunately, it could not be used reliably. The residuals were not normally distributed and presented heteroskedasticity in their variance. Still, it is useful to share it for research purposes. Finally, it is important to mention that the DCC-MGARCH model has been used in literature, but mostly to explain financial variables, which are volatile. The model will be specified in the next paragraphs.

This paper has two main objectives: first, to show whether the UK CPF has been more effective in tackling the CO_2 emissions in the UK than the EU ETS in Germany. A coefficient between the carbon price and the CO_2 emissions will be calculated to determine the magnitude of this relationship in each country. Second, test whether there are spillovers effects between the carbon price and electricity produced by renewables in these two countries. The spillover effect will be calculated by the same econometric model. The magnitude of the spillover effect is important since the goal of Germany and the UK is to produce clean electricity in the long term. Therefore, the carbon price must promote the elimination of GHG emissions and not the switch from coal-fired plants to gas. Finally, the seasonality effect is being considered.

The weekly logarithmic variation of energy and economic variables are used. This approach goes in line with (Manera, Nicolini, & Vignati, 2013), who employed the same econometric model to test correlations among energy commodities. The energy variables used price of natural gas, coal, EU ETS and UK CPF, the electricity demand, the electricity production from solar, wind, and nuclear sources; and CO_2 emissions of Coal, Natural Gas, and Lignite. The Coal-to-Gas price ratio has been used by (Gugler et al., 2021), (Abrell et al., 2021), and many others because it represents the cost relationship between the two most important electricity fuels. (Gugler et al., 2021) and (Koch et al., 2014) utilized the production from renewable sources in their models. The electricity production from renewables influences the ones from coal and natural gas because the are ranked in the merit-order curve. The economic variables used are the prices of the Financial Times Stock Exchange 100 (FTSE 100), which represents the 100 biggest companies listed in the London Stock Exchange, and the *Deutscher Aktien Index* (DAX), which represents the 30 largest companies listed in the Frankfurt Stock Exchange. Several authors have included economic variables in their analysis of the carbon price. For example, (Koch et al., 2014) employed the returns of the European stock exchange and concluded that the EU ETS was not affected by demand shocks. Still, there is not a homogeneous consensus of the effects of an economic recession on the carbon price. During the time frame analyzed in this document, the Covid-19 economic crisis took place.

As the carbon price is time-varying, it is crucial for its correct modeling to 1) measure the volatility of the electricity production per source and 2) consider the economic variables that have an impact on their price. For the first point, the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model is useful. It assumes that not only past variations but also the volatility of the CO_2 emissions has an impact on the present value of the CO_2 emissions. For the second point, the GARCH multivariate Dynamic Conditional Correlation model (DCC-GARCH) considers that past variations and volatility of the other variables employed, such as the carbon price, affect the CO_2 emissions. The added value of the multivariate DCC-GARCH model is that both points can be tested per variable. Hence, the model will measure the impact that previous returns and deviations of each variable have on itself, and how these affect the other variables dynamically.

The univariate GARCH model specified by Engle (2013) is as follows:

(i) $r_t = m_t + \sqrt{h_t}\varepsilon_t$
(ii) $h_{t+1} = \omega + \alpha(r_t - m_t)^2 + \beta h_t = \omega + \alpha h_t \varepsilon_t^2 + \beta h_t$

The first equation (i) represents the returns of the financial asset (r_t) in terms of the average of the returns (m_t) and the residuals ($\sqrt{h_t}\varepsilon_t$). h_t represents the variance of the residuals, and ε_t the error term, which has a variance of one. The second equation (ii) is the GARCH model for the variance of the residuals (h_{t+1}) which is explained by the past realizations of itself (h_t) and the constants ω, α, and β. To estimate the constants ω, α, and β; the model updates the previous forecast of h and the residual (Engle, 2013). The way the model optimizes is considering weights of ($1 - \alpha - \beta$, α, β). Note that the weight of ω is calculated by difference the ($1 - \alpha - \beta$).

In this paper, the Dynamic Conditional Correlation Multivariate GARCH (MGARCH-DCC) is applied, which allows the use of many variables without increasing the model's complexity. The MGARCH-DCC model is used in this paper for the following reasons: 1) the model captures the heteroscedasticity of the variance, and 2) estimates the conditional correlations between electricity variables that vary over time (Bali and Engle (2010); Ewing, Malik, and Ozfidan (2002)). For instance, the correlation between the carbon price and CO_2 emissions may decrease during an economic crisis, because demand for electricity generated by coal may shrink due to economic depression instead. The MGARCH-DCC model is determined in two steps. First, each variable is estimated following a univariate GARCH model. Second, the correlation among all the variables is calculated. This dynamic process is expressed by the variable $\rho_{ij,t}$ that alters the MGARCH model as shown below.

(iii) $h_{ij,t} = \rho_{ij,t}\sqrt{h_{ii,t}h_{jj,t}}$

The variable $\rho_{ij,t}$ represents the dynamic conditional correlation among all the variables included in the MGARCH. The i represents the number of variables considered in the model. For this paper, there are six variables per country: clean electricity generation, CO_2 emissions from coal, gas and lignite, carbon price, electricity demand, coal-to-gas price ratio and the stock market index. The j represents the same as i, but the distinction is made in order to emphasize that the model is expressed in matrix terms and that different combinations of the variables are considered. The t represents the day of the observations since the MGARCH is a time-series model.

Therefore, the MGARCH-DCC specified by Engle (2002) is comprised as follows:

(iv) $X_t = \mu_t + H_t^{1/2}\varepsilon_t$
(v) $H_t = D_t R_t D_t$
(vi) $R_t = Q_t^{*-1} Q_t Q_t^{*-1}$
(vii) $D_t = diag(\sqrt{h_{11,t}}, \ldots, \sqrt{h_{jj,t}})$
(viii) $Q_{t+1} = (1-\alpha-\beta)\$ = Q + \alpha Q_t + \beta\delta_{i,t}\delta_{j,t}$

The fourth equation (iv) represents the univariate GARCH model with the inclusion of the matrix of time-varying conditional covariance ($H_t^{1/2}$). This equation (iv) expresses the vector of returns (X_t) and the vector of conditional returns (μ_t) per asset, where ε_t is the vector of standardized residuals. H_t which is represented by the fifth equation (v) is a matrix of time-varying conditional covariance that is built by the matrices D_t and R_t. The diagonal matrix D_t which is shown in the seventh equation (vii) consists of the standard deviations of the estimated returns by the univariate GARCH model.

$$D_t = \begin{pmatrix} \sigma_{1,t}^2 & 0 & \cdots & 0 \\ 0 & \sigma_{2,t}^2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \sigma_{i,t}^2 \end{pmatrix}$$

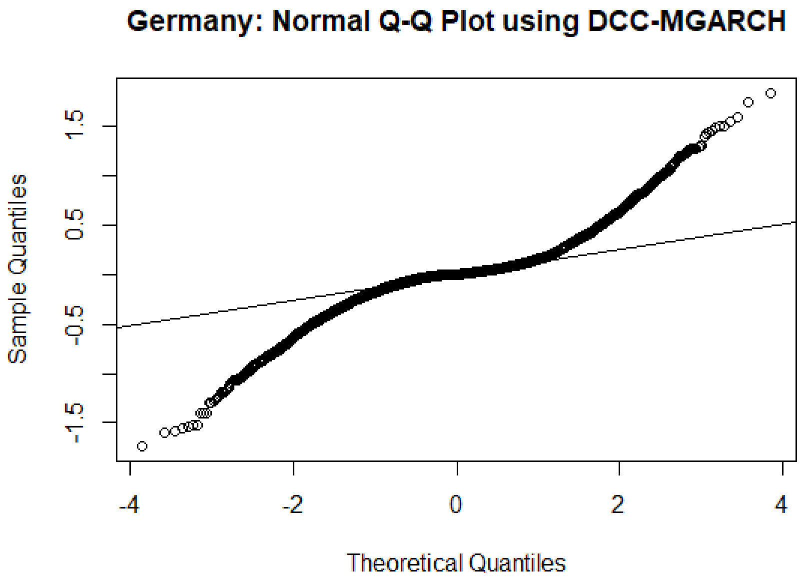
The eighth equation (viii) shows Q_{t+1} which represents the unconditional correlation matrices that build the R_t, which is a symmetric conditional correlation matrix. This equation (viii) exhibits the coefficients that are relevant to test our hypotheses. R_t is represented by the sixth equation (vi). Finally, the model obliges that α and β are non-negative and that the sum of both is lower than 1.

$$R_t = \begin{pmatrix} 1 & \rho_{12,t} & \cdots & \rho_{1i,t} \\ \rho_{12,t} & 1 & \cdots & \rho_{2i,t} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{1i,t} & \rho_{2i,t} & \cdots & 1 \end{pmatrix}$$

The alpha (α) represents the spillover effect, which shows if the variation in the volatility of a carbon price impact another. For example, if there is an abrupt change in the price of price of the EUA or UK CPF, the α will measure how this increase in volatility impacts the CO_2 emissions. The beta (β) outlines the persistent effects that exhibit if this variation has a future repercussion in another asset. For instance, if there is an economic crisis, the volatility of carbon price would increase positively. This could lead to a increase in the volatility of CO_2 emissions that would last for many periods ahead, as the carbon price is considered a cost for the generation of electricity by fossil fuels. These two variables are useful to test if the carbon's volatility affects the volatility of the CO_2 emissions and if the impact is persistent enough to influence persistently the future development of the CO_2 emissions. These effects are important for the industry, because clean electricity investments require a stable carbon price to be profitable (Hirst, 2018). Under the multivariate model, the α is represented by the variable *dcca* and the β by *dccb* and they test the effect among the six variables.

Q-Q Plots for Residuals of the DCC-MGARCH model

As mentioned above, the model was not used since its residuals are not normally distributed. Below are the Q-Q plots which show this behaviour.



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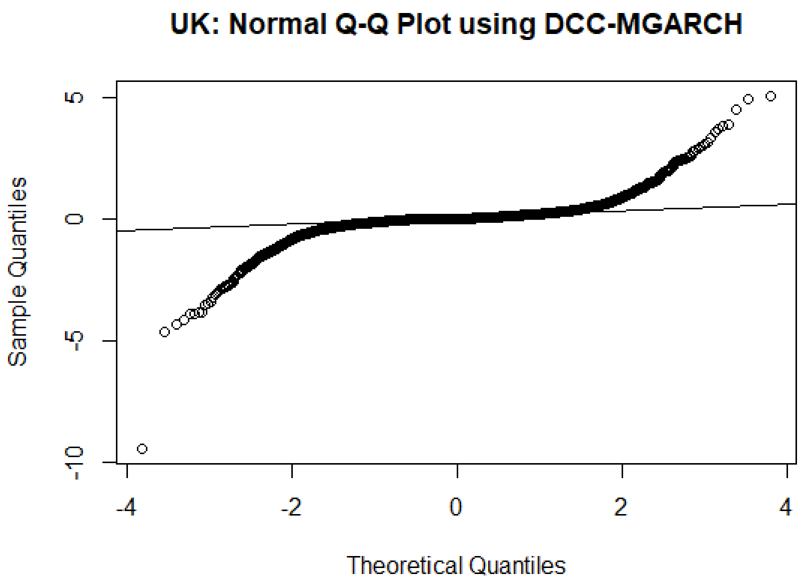

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