

Preface

The idea of writing this book naturally came after a discussion with my editor, whom I warmly thank for making this project possible. This book should be extremely useful for researchers and working professionals (trading managers, energy and commodity traders, quantitative analysts, consultants, utilities) in the fields of econometrics and carbon finance. We define carbon markets as the environmental markets created to regulate the emissions of greenhouse gases (including CO₂), such as the European Union Emissions Trading Scheme (EU ETS) and the Kyoto Protocol (more precisely the Clean Development Mechanism, CDM).

This book is intended for readers with a basic understanding of time series econometrics (such as the linear regression model, vector autoregression, and cointegration). Useful textbooks to refresh concepts on this matter are Gujarati (*Basic Econometrics*, McGraw-Hill) and Hamilton (*Time Series Analysis*, Princeton University Press). It can be used for teaching econometrics applied to carbon markets at undergraduate or postgraduate levels (M.Sc., MBA), and as a reference for professionals.

The content of this book has been presented during lectures on the econometrics of energy markets and on commodity finance at the University Paris Dauphine. It draws on feedback and practical exercises developed with former M.Sc. Students, to whom this book is likewise dedicated.

Through the analysis of the EU ETS and the CDM, the book shows how to use a variety of econometric techniques to analyze an evolving and expanding carbon market sphere worldwide. The book offers a mix of knowledge on emissions trading with practical applications to carbon markets. It covers the stylized facts on carbon markets from an economics perspective, as well as key aspects on pricing strategies, risk and portfolio management. On the one hand, it contains useful information on how to interpret the historical development of the carbon price (until the present time). On the other hand, it is instructive to teach students (advanced undergraduates, M.Sc., MBA) and researchers how to use these techniques to perform similar exercises as carbon markets evolve and expand. Therefore, these techniques may be re-used as new national and regional schemes appear in the near future of environmental regulation (China, USA, etc.).

Chapters 1 and 2 provide an accessible introduction to the fundamentals of time series econometrics to support anyone new to the material in learning the princi-

ples of carbon markets. Starting in Chap. 1 with the analysis of descriptive statistics for carbon prices, the econometrics learning process is regular throughout the book. Chapter 1 has a broad coverage, as the book starts with the review of international climate policies (and thus of national and regional carbon markets initiatives as in the US, Japan, China, Australia, etc.). In addition, it contains a brief introduction to the mechanism of emissions trading, and the main features of the European carbon market. It includes little econometric techniques (only a review of descriptive statistics), but it contains nonetheless useful background information for the book.

Chapter 2 deals with carbon price drivers (mainly institutional decisions, energy prices and extreme weather events) in the context of the linear regression model. It covers perhaps the most interesting topic concerning CO₂ prices, i.e. what are the relevant price fundamentals on carbon markets? Starting with the use of dummy variables and the Bai-Perron structural break test, it relies heavily on the linear regression model to show the influence of other energy prices. Weather events are accounted for by using threshold variables (above or below a given temperature). The Appendix contains a useful review of the multivariate GARCH modelling framework applied to energy and CO₂ prices.

Chapters 3 to 6 offer a smooth transition from being taught the basics in time series econometrics to actively research carbon markets for term-papers or dissertations for advanced undergraduate and/or postgraduate students (M.Sc., MBA). Chapter 3 deals with an equally important topic: what is the relationship between the newly created emissions allowances and the pre-existing macroeconomic environment? This topic is tackled first by looking at the link between the equity/bond markets and the emissions market in a GARCH modeling framework. Then, the broad links with macroeconomic, financial and commodity spheres are captured in factor models. Next, the link with industrial production is studied by resorting to nonlinearity tests, threshold models and Markov regime-switching.

Chapter 4 focuses on the Clean Development Mechanism, which may be seen as a proxy of 'world' carbon prices in the absence of post-Kyoto agreements. Besides the description of the contracts, this chapter details the use of vector autoregression, Granger causality, cointegration techniques (with the EU carbon price) and the Zivot-Andrews structural break test. Arbitrage strategies between the European market and the CDM are studied in a GARCH modeling framework with microstructure variables in order to explain the existence of the 'EUA-CER spread'. The Appendix illustrates the use of the Markov regime-switching models with EUAs and CERs.

Chapter 5 deals with risk-hedging strategies and portfolio management. The main risk factors related to carbon assets are summarized. The measure of risk premia in CO₂ spot and futures prices is detailed based on commodity markets models and linear regressions. Besides, carbon price risk management strategies are described by the means of an econometric analysis of the factors influencing fuel-switching in the power sector. Finally, portfolio management techniques with carbon prices are explained in details with standard mean-variance optimization techniques. The Appendix recalls how to use option prices for risk management by computing implied volatilities.

Chapter 6 contains more advanced econometric techniques. It investigates whether or not the volatility of carbon prices shifts as CO₂ futures contracts reach

maturity. Three approaches are used as a proxy for volatility in order to shed light on this issue: GARCH models, net cost-of-carry, and realized volatility. The so-called Samuelson hypothesis is tested in a regression framework, by accounting for seasonality and liquidity issues. The Appendix covers statistical techniques that are useful in order to detect instability in the volatility of carbon prices.

In order to replicate part of the empirical applications detailed in the various chapters, this book recommends the use of the R software. R is a free software designed for statistical and econometric analysis. Its installation is extremely easy under any operating software, and comes with a documentation. The packages that are required to duplicate the results must be downloaded from the Comprehensive R Archive Network (CRAN) and pre-installed by the user with the command `install.packages()` and by following the command prompt. Finally, the necessary data and R codes can be found on the author's website: <http://sites.google.com/site/jpchevallier/publications/books/springer/>.

This companion website with hyperlinks to data and computer codes related to the models, and the replication of examples discussed in the book (where it is relevant) ensure that the reader is able to develop his/her programming skills. Besides, this data warehouse with computer codes constitutes an original means of disseminating knowledge. The interested reader will also find a Frequently Asked Questions (FAQ) section on the website.

For developing R packages used in this book, I wish to thank Achim Zeileis, Friedrich Leisch, Bruce Hansen, Kurt Hornik, Christian Kleiber, Patrick Brandt, Bernhard Pfaff, Harald Schmidbauer, Angi Roesch, Vehbi Sinan Tunalioglu, Diethelm Wuertz, Yohan Chalabi, Michal Miklovic, Chris Boudt, Pierre Chausse, Douglas Bates, Ladislav Luksan, as well as the R core development team: <http://www.r-project.org/>.

In terms of course use, this book may be appealing to courses in finance, such as principles of financial markets, financial economics and financial econometrics. It will also be relevant to courses in energy, environmental and resource economics, as it covers the EU ETS and the Kyoto Protocol which constitute landmark environmental regulation policies. Since the carbon price constitutes a new commodity, it will also be eligible to courses on commodity markets and risk management on these markets. Finally, empirical applications may be re-used in exercises for standard (introductory) applied econometrics courses (such as time series analysis). Problem sets (with solutions manual) are presented at the end of the relevant chapters, and presentation slides for each chapter are available for instructors on the author's companion website.

Last but not least, I wish to thank many people with whom I have been interacting over the years, either in carbon finance or in academia, which led me to develop the skills and material necessary to write this book: Emilie Alberola, Benoit Cheze, Pascal Gastineau, Florian Ielpo, Maria Mansanet-Bataller, Morgan Herve-Mignucci, Benoit Leguet, Anais Delbosc, Raphael Trotignon, Benoit Sevi, Yannick Le Pen, Derek Bunn, ZongWei Luo, ZhongXiang Zhang, Denny Ellerman, Olivier Godard, Katheline Schubert, Natacha Raffin, Philippe Quirion, David Newbery, Fabien Roques, Sam Fankhauser, Simon Dietz, Eric Neumayer, Luca Taschini,

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