Valuation of CO2 Option Contracts in the European Emission Trading Scheme

Master Thesis in Quantitative Finance

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Executive Summary

The increasing concentration of greenhouse gases, such as carbon dioxide, in the atmosphere is largely being held responsible for the alarming phenomenon of global warming. Scientists as well as politicians have come to accept that climate change is indeed linked to human activities. The United Nation's response was the establishment of what is known today as the Kyoto Protocol. This agreement presents legally binding commitments for the reduction of greenhouse gases by developed countries and economies in transition. To date, the Kyoto protocol has been ratified by over 180 countries worldwide.

One of the key mechanisms for reducing CO2 emissions included in the protocol is the trading of emission allowances within organized financial markets. The European Emission Trading Scheme EU ETS is an example of a cap-and-trade emission trading scheme which was implemented to facilitate the realization of the European Union's commitment to the Kyoto Protocol.

As the EU ETS is a politically established and emerging financial market, it is still characterized by illiquidity and efficiency issues. Therefore the evaluation of proper hedging strategies based on standard financial securities is required. This thesis' main objective is the development of an appropriate hedging strategy to reduce CO2 price uncertainty and assess the hedging performance in value at risk forecasts. The hedging strategies presented in this thesis focus exclusively on CO2 price risk.

In the course of this, the issue of pricing carbon futures and options on futures within the EU ETS is addressed. Analyzing carbon price behavior is critical for understanding how this new market functions and what risks are involved. Several stochastic processes are selected to describe the observed carbon futures prices and a calibration on the sample data from 2005-2009 is performed.

Empirical analysis indicates that emission allowance futures log returns have a leptokurtic distribution with heavy tails and negatively skewed log returns.

Among the stochastic processes examined by maximum likelihood estimation, geometric Brownian motion augmented by jumps performs best for replicating the observed log-returns. Jumps refer to sudden shocks in the variable that occur randomly over time.
The mean-reverting Ornstein-Uhlenbeck process comes in second place when considering the entire time period since April 22, 2005, i.e. the launching date of carbon permits on ECX. Mean-reversion describes a tendency for a stochastic process to return to a long-run average value over time.
The standard geometric Brownian motion fails to incorporate skewness and fat tails, since it assumes normally distributed log-returns. Thus, it demonstrates lower values for both the Akaike's Information Criterion and the Bayesian Information Criterion.

Spread option valuation in energy markets is challenging. However, spread options in a market such as EU ETS may be particularly relevant for hedging purposes. Spark and dark spreads represent the differential between the price of electricity and the price of primary fuels. Thus, they can be used to replicate the physical reality of a power plant in financial terms. With the introduction of emission allowances, these spreads had to be adjusted by carbon costs.

An extensive variety of mathematical tools have been used in the analysis of spread options. Due to the non-storability of electricity, futures based replication is necessary when valuing electricity derivatives by constructing replication portfolios. In this thesis, closed-form solutions for the spread option price - when the prices of the underlying assets follow either geometric Brownian motion or mean reverting processes - are presented. Since both are only applicable for zero strike price options, the Bachelier approximation is introduced as well. Bachelier approximation assumes that the underlying assets follow arithmetic Brownian motion and is able to cope with non-zero strike prices.
Numerical experiments reveal that as time to maturity increases and as correlation decreases, so do the differences between the Bachelier model and other

approaches, such as Monte Carlo simulation, assuming geometric Brownian motion.

Clean spark spread options can be used to manage the carbon price risk exposure of a gas-fired plant since they represent its payoff. This thesis presents a dynamic delta hedging strategy based on clean spark spread call options. Delta hedging refers to a strategy that aims to reduce the risk associated with price movements in the underlying asset. A delta neutral porfolio is insensitive to the changes in the price of an underlying asset. However, delta hedging's effectiveness declines as the prices fluctuate from the current market conditions. Dynamic hedging continually updates the hedging position in order to closely track the price development. Indeed, simulation of the hedging strategy shows that the daily rebalancing of the portfolio improves the VaR forecasts of the hedging error as compared to no rebalancing. The consideration of transaction costs in the simulations makes dynamic hedging less favorable, since it entails a tradeoff between cost and risk. Fixed costs may easily be incorporated by using the Bachelier approximation. Results of these simulations must be interpreted with caution, however, as the Bachelier model is only accurate for low time to maturity and high correlation. The presented delta hedging strategy focuses on the carbon price risk. Inluding electricity and fuel price risk as well would be a possibility to broaden the scope of the study.