Risk Aversion and Institutional Information Disclosure on the European Carbon Market

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Abstract

This article evaluates the impact of information disclosure on changes in investors' risk aversion on the European Carbon Market using the newly available option prices dataset. Since the price collapse that occurred on April 2006 due to the verification of 2005 emissions, investors are concerned by the emergence of future shocks related to the negotiation of National Allocation Plans for Phase II. Following the methodology existing for stock indices, we recover empirically risk aversion adjustments on the period 2006-2007 by estimating first the risk-neutral distribution from option prices and second the actual distribution from futures. Our results show evidence of a dramatic change in the market perception of risk around yearly compliance events that has not been assessed yet.

JEL Codes: C14; G14; Q54

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1 Introduction

The European Union Emissions Trading Scheme (EU ETS) was created on January 1, 2005 by the European Commission (EC) to foster early compliance with the greenhouse gases emissions reduction targets agreed in the Kyoto Protocol. Its successful implementation is currently being evaluated against its simplicity and the fairly transparency of the trading mechanisms instored. As such, the EU ETS covers up to 46% of CO_2 emissions from European energy-intensive industries. Every year, each industrial plant is allocated EU allowances (EUA)[1] corresponding to its cap and must restitute as many allowances as verified CO_2 emissions. 2.2 billion of allowances were allocated to 10,600 installations across 27 EU Member States in 2005-2007 which are tradable all around Europe on exchanges and by over-the-counter. The next two phases of the scheme are interconnected[2] and will take place during 2008-2012 and 2013-2020.

Yet this scheme raises various design issues related to the efficiency and equity of such market-based instruments. An efficient system leads to the equalization of marginal abatement costs among participants, yielding a unique market price that acts as a medium-term signal for investors to make cost estimates of delivering different levels of energy efficiency and how much emissions abatement to undertake. An equitable system consists in allocating allowances based on a uniform criteria that is mostly perceived as fair and agreed upon by the various stakeholders.

During its Pilot Phase, the EU ETS has failed to provide these right incentives. First, after a price "collapse" on April 2006 due to the publication of the 2005 verified emissions data by the EC, the EUA spot price of maturity December 2007 has been asymptotically decreasing towards zero because of the impossibility to transfer allowances to the next period. This provision may seem justified *ex-ante*, since nobody had a clear idea of the exact number and the volume of traded allowances, but it prevented the scheme from delivering its price signalling message in terms of CO_2 abatement efforts needed in the EU to meet the Kyoto targets. Second, the allocation of allowances based on grandfathering and prior use rules did not achieve its equity objective as some sectors such as power producers were far more constrained than other participants who received an amount of allocation close to their business-as-usual scenario.

Thus, the EU ETS Review[3] pointed out the necessity for the EC to act more as the central authority entitled to set firmly emissions caps for Phase II and to restore the scarcity of allowances equally among sectors, including the sectors that will be included in the scheme in Phase III[4].

The role of coordinator, educator and enforcer played by the EC is central to the analysis of investors' risk aversion developed in this paper. At the start of the EU ETS, most of the information available for trading was deemed as speculative. Consequently, we attempt to characterize investors' hedging strategies for this new carbon commodity by asking the following central question: can we statistically identify a shift in investors' risk aversion around yearly compliance events imposed by the EC?

To our best knowledge, this analysis constitutes the first tentative assessment of risk behavior on the EU ETS since it is based on newly available plain vanilla option prices data on the European Climate Exchange which transfer the risk of financial exposure between market agents. Chesney and Taschini (2008) provide an application of CO_2 price dynamics modelling to option pricing, but their study is only based on numerical simulations.

We retrieve empirically investors' risk aversion on the EU carbon market based on the relationship that exists with the risk-neutral and historical probabilities as detailed by Jackwerth (2000). Yet our methodology to recover risk aversion from option and futures prices slightly differs from Jackwerth (2000) whose dataset with monthly frequency would yield to few observations on this new commodity market. Rather, we base our analysis on non-parametric kernel regression (Aït-Sahalia and Lo (2000), Cont and da Fonseca (2002)) to estimate the risk-neutral probability distribution and on an asymmetric GARCH model to estimate the historical probability distribution (Rosenberg and Engle (2002)). Such an approach proved to be useful in documenting changes in implied risk aversion for major equity indices.

We find some evidence that shifts in investors' risk aversion are readily observable on the EU ETS following the disclosure of institutional information by the EC on April 30 of each year that corresponds to compliance results. Moreover, we observe different lower levels of volatility for EUA price series of all maturities after the 2006 compliance period. This latter result suggests that institutional information disclosure has a strong market effect. Besides, our results indicate periods of increasing markets coincide with periods of higher volatility. This inverted leverage effect reveals that, contrary to equity markets, the risk is associated with increasing allowance prices in a context of a low environmental constraint. Expectation building is becoming more efficient on the EU carbon market since market agents gradually integrate accurate information published by the EC concerning the level of CO_2 emissions compared to allocated allowances, be it at the installation or aggregated levels. Thus, we highlight the role played by the regulator in changing market participants' expectations concerning amendments of the scheme.

The remainder of the paper is organized as follows. Section 2 discusses the expected investors' risk perception with respect to institutional design features of the EU ETS. Section 3 details the estimation methodology to recover the risk-neutral and historical probabilities from option and futures prices. Section 4 discusses the empirical results. Section 5 concludes.

2 Risk Behavior on the EU Carbon Market

The characterization of risk behavior and risk management strategies on the emerging EU carbon market constitutes an important field of research for several reasons.

First, the rents distributed to existing incumbents on a "first-come, first-served" basis represents a market value of €40 billion that was created at the same time as CO_2 emissions were capped. This allocation methodology, also known as grandfathering, is the most frequently observed since the market determines the size and nature of property rights and there are less political pressures to instore such as scheme. Its main benefits lie in the fact that it recognizes incumbents and specific non-deployable investments, rewards first-movers and economizes transaction costs. Since January 1, 2005 carbon allowances therefore form another asset in commodities against which industrials and brokers need to hedge. As the volume of transaction on the EU ETS has been increasing steadily from 262 million tons in 2005 to 1,443 million tons in 2007, this trading activity reflects market participants' progressive learning of this new financial market. Thus, we are interested in examining closely the formation of investors' risk appetite related to the diffusion of institutional information.

Second, during Phase I of the EU ETS (2005-2007), spot prices experienced a high level of volatility around each compliance event. Since industrial installations have the obligation to surrender to the EC the exact number of allowances that matches their verified emissions each year around end of March, this institutional compliance event may be used as the cornerstone of each major change in investors' risk aversion. The official report by the European Commission is disclosed by mid-May[5], but installation operators have already a fair amount of information between the publication of their own report and the compilation of verified emissions by the EC to approximate the global level of emissions relative to allowances allocated and to adjust their anticipations. By the end of April 2006, a spot price correction of 54% within four days followed the announcement by the EC that CO_2 emissions were approximately 3% lower than the allocated allowances during the 2005 compliance period (Ellerman and Buchner (2008)). This particular kind of institutional event led to a shift in investors' risk aversion that we aim at capturing in this paper.

Third, carbon allowances exhibit strong characteristics of being a non-standard commodity (Paolella and Taschini (2008)), since installations do not need to physically hold allowances to produce but only to match them with verified emissions for their yearly compliance report to the EC. Consequently, the probability of a potential illiquidity trap exists if market participants face a market squeeze during the compliance event. This specificity of EU allowances adds another line of argument to justify our specific interest in the formation of risk aversion and purchasing strategies by market participants around compliance events.

On October 2006, following multiple EC announcements[6] to tighten allocation caps for Phase II, we observe a divorce between the EUA spot and futures price series. While the EUA spot price pattern was decreasing towards zero until December 2007, the EUA futures price series stabilized around €20 per ton. This price signal is currently sustained on the medium-term by the decision of the European Council to maintain the European carbon market at least until 2020. Thus, the futures price series seems to reflect better the dynamics behind investors' anticipations and hedging strategies, which explains why we have decided to work with futures instead of spot prices.

It appears interesting to highlight for the purpose of this study that, around each yearly publication of verified emissions results by the EC, investors' anticipations with respect to risk are changing. Indeed, despite its recent creation, Seifert et al. (2007) emphasize that most market agents, and not only large market players such as power producers, are attempting to estimate accurately CO_2 emissions levels and abatement efforts on the EU ETS. In what follows, we test the hypothesis that strong reversals in investors' anticipations occur during the 2006 compliance event[7]. Moreover, we expect the level of volatility to decrease after the diffusion of information by the EC which tends to dissipate previously misleading trading information on this new market.

In this section, the discussion on EU allowance characteristics in terms of trading patterns and price developments leads us to argue that institutional information disclosure by the EC has a clear effect on adjustments in risk behaviors since it provides reliable market updates on agents' positions in terms of actual CO_2 emissions with respect to allocated allowances. In the next section, our estimation strategy is detailed to identify statistically those changes in investors' risk aversion that are expected to occur around yearly compliance events.

3 Estimation Methodology

As presented in Bertholon et al. (2007), there are several ways to deal with the risk aversion estimation problem. Absolute risk aversion can be expressed in terms of the historical and risk-neutral probability distributions (Aït-Sahalia and Lo (2000), Jackwerth (2000), Rosenberg and Engle (2002)):

$$RA(x) = \frac{f'(x)}{f(x)} - \frac{q'(x)}{q(x)} \tag{1}$$

where $q(x)$ is the risk neutral density and $f(x)$ is the historical density across states. It is easy to see that once two of them are known, the third one is readily available as a by-product. Here, we have at hand enough data to estimate both the risk neutral and historical distributions without making assumption about the shape of investors' risk appetite. Thus, risk aversion will be deduced from our estimation of the risk neutral and historical probability measures. Following the terminology established in Bertholon et al. (2007), this approach fits the "Risk-Neutral Constrained Direct Modelling" strategy, *i.e.* we make limited assumption on the risk neutral and historical distributions and no assumption on the pricing kernel.

Following Aït-Sahalia and Lo (2000), we estimate the risk neutral distribution non-parametrically, while the historical distribution is recovered from a semi-parametric GARCH procedure (Barone-Adesi et al. (2007), Rosenberg and Engle (2002)). As explained above, from these estimates we will deduce an empirical estimate of risk aversion. This methodology will then allow us to investigate the empirical characteristics of investors' risk aversion on the European carbon market, along with its potential shifts around yearly compliance events.

Let us first detail how to recover both the risk-neutral and historical probability distributions.

3.1 Risk Neutral Probability Distribution

Under no arbitrage restrictions, the price of an European call is:

$$C(\tau, K) = B(\tau) \int_{-\infty}^{+\infty} (S_T - K)\ q(S_T)\ \mathrm{d}S_T = B(\tau)\ \mathbb{E}^Q\ [(S_\tau - K)^+] \quad (2)$$

where $C(\tau, K)$ is the premium for a call option of time to maturity τ and strike price K, S is the underlying asset price and r is the risk-free interest rate. $B(\tau)$ is the price of a zero coupon bond with maturity τ and represents the corresponding discount factor, *i.e.* $B(\tau) = e^{-r\tau}$. $\mathbb{E}^Q[.]$ denotes the expectation computed using the risk-neutral distribution. Following Breeden and Litzenberger (1978), we have:

$$\frac{\partial^2 C(\tau, K)}{\partial K^2} = B(\tau)\ q(S_T | S_T = K). \quad (3)$$

Equation (3) describes the formal relationship between the second derivative of the call price with respect to the strike price and the risk-neutral density. Since we are mostly interested in recovering the "average" pricing kernel in the option market, we propose to use Aït-Sahalia and Lo (2000) non parametric estimator to the risk neutral density. This estimator uses the link between implied volatility and the risk-neutral distribution: since both implied volatility and risk neutral distribution depend on the moneyness, it is possible to infer the risk neutral distribution from implied volatilities series. When $\sigma(K)$ is a function of the strike that is twice differentiable, using the Black-Scholes model and eq.(3) result, Andersen and Wagener (2002) showed that:

$$q(S_\tau|S_\tau = K) = e^{r\tau}\frac{\partial^2 C}{\partial K^2} \tag{4}$$

$$= \frac{1}{\sigma(K)K\sqrt{\tau}} + \left(\frac{2d_1}{\sigma(K)}\right)\frac{\partial\sigma}{\partial K} + \left(\frac{d_1 d_2 K\sqrt{\tau}}{\sigma}\right)\left(\frac{\partial\sigma}{\partial K}\right)^2 + K\sqrt{\tau}\frac{\partial^2\sigma}{\partial K^2}. \tag{5}$$

For $\sigma(\tau, K)$ to be expressed as a function of the strike price, it may be estimated either parametrically with a polynomial[8] or non-parametrically. Aït-Sahalia and Lo (2000) recommend the use of a non parametric estimator of the volatility surface (see also Cont and da Fonseca (2002)). This estimator is particularly adapted to situations where we do not need a day-by-day estimator of this probability density function, but an estimator of the average risk neutral distribution over a large time period. This approach is close to what may be found in Jackwerth (2000). We propose to use the non-parametric approach that also offers the advantage to be more robust to market anomalies which are very likely to occur on such a new commodity market. Thus, we introduce a non-parametric Nadaraya-Watson estimator with $k = \frac{K}{S}$ defined as the moneyness and τ fixed as in Cont and da Fonseca (2002):

$$\sigma(k,\tau) = \frac{\sum_{i\ j} K\left(\frac{\tau-\tau_i}{h_1}\right)\ K\left(\frac{k-k_j}{h_2}\right)\ \sigma(\tau_i, k_j)}{\sum_{i\ j} K\left(\frac{\tau-\tau_i}{h_1}\right)\ K\left(\frac{k-k_j}{h_2}\right)} \tag{6}$$

with

$$K(x) = \frac{1}{\sqrt{2\pi}}\ e^{-\frac{1}{2}x^2} \tag{7}$$

the Gaussian kernel. $\{h_1, h_2\}$ are bandwidth parameters that determine the degree of smoothing. As pointed out by Cont and da Fonseca (2002), too small values will lead to a bumpy surface while too large ones will smooth away important details. On the optimal choice of these parameters, we follow the methodology used in the latter paper. Once we have this non parametric estimator of implied volatility, we are able to derive it with respect to the strike price and then use it in eq. (5) to finally recover the risk neutral distribution for a given horizon τ. It is noteworthy to remark that this methodology imposes martingality restrictions as a by-product. These restrictions are essential to recover the risk neutral distribution (Jurczenko et al. (2001)).

Finally, we recall how to obtain implied volatility series from option prices. Building on the previous notation, $C(\tau, K)_{obs}$ is the observed call option price and $C(\tau, K, \sigma)_{BS}$ is the Black-Scholes (BS) price computed using the implied volatility σ. By definition, we have $C(\tau, K)_{obs} = C(\tau, K, \sigma)_{BS}$. The implied volatility of the strike price is obtained by numerically inverting the BS formula, which can be done by solving:

$$\min_{\sigma} \left(C(\tau, K)_{obs} - C(\tau, K, \sigma)_{BS}\right)^2 \tag{8}$$

Then, allowing σ to be a function of the strike price, we may use eq.(3) to recover the risk-neutral distribution.

Next, we present our methodology to recover the historical distribution.

3.2 Historical Probability Distribution

There exists an emerging body of literature on the spot-forward parity in the EU ETS. Seifert et al. (2007) reveal a very steep spot price volatility increase when coming toward the end of the trading period. Borak et al. (2006) also pointed out that the term structure for allowance prices changed from initial backwardation to contago and is subject to abrupt changes of expectations. This situation provides a first element of justification to use futures instead of spot prices series in our dataset. Besides, as explained in Section 2, futures exhibit a more coherent price pattern since the April 2006 price collapse that occurred for all maturities. This approach is also in line with Paolella and Taschini (2008) who argue that the study of spot price dynamics is inadequate due to early political uncertainties on the allowance market. That is why we prefer to consider futures contract prices of maturity December 2008 and December 2009[9]. As for the estimation methodology, Benz and Truck (2006) and Paolella and Taschini (2008) strongly support the use of GARCH specifications to model the returns of CO_2 emission allowances which is also developed below.

Following the literature dedicated to the stock market, we choose to model the historical distribution using a semi-parametric asymmetric GARCH(p, q) model as in Barone-Adesi et al. (2007). We discuss the goodness of fit of the chosen model compared to other specifications for the CO_2 return series in the next section. Note the methodology adopted by Jackwerth (2000) is not applicable because the monthly frequency used would lead to few observations. Besides, it is worth underlining that unlike Rosenberg and Engle (2002) and Jackwerth (2000) we use longer term option prices with a 16-month investor horizon[10] to display our results.

The estimated model is:

$$\begin{aligned} r_t =& \mu + \epsilon_t \\ \sigma_t^2 =& \omega_0 + \omega_1 \epsilon_{t-1}^2 + \omega_2 \sigma_{t-1}^2 + \delta \max(0, -\epsilon_{t-1})^2 \end{aligned} \tag{9}$$

with $\epsilon_t \sim N(0,1)$. If $\delta > 0$, we have $Cov(r_t - r_{t-1}, \sigma_{t-1}^2 - \sigma_{t-2}^2) < 0$ to take into account the asymmetry also known as the skewness effect in stock price dynamics and the leverage effect in financial economics. The model is estimated in a Pseudo Maximum Likelihood (PML) framework by assuming returns are Gaussian. As Gourieroux et al. (1984) put it, estimating by PML will lead to unbiased estimates even if the probability distribution function does not necessarily contain the true distribution. Barone-Adesi et al. (2007) and Rosenberg and Engle (2002) proved the robustness of this approach. The estimates covariance matrix is estimated using the BHHH matrix (see Berndt at al. (1974)). We then recover the estimated residuals and bootstrap them to simulate sampled paths for any maturity of interest. Using these simulated returns, we estimate the conditional historical distribution density using the following Gaussian kernel:

$$f(S) = \frac{\sum_j K\left(\frac{S_j - S}{h}\right) S}{\sum_j K\left(\frac{S_j - S}{h}\right)}. \tag{10}$$

As in Jackwerth (2000), we select the following bandwidth parameters:

$$h = \frac{1.8\sigma}{\sqrt[5]{n}} \tag{11}$$

where S is a point of the future value of the asset price support, h is the kernel bandwidth, σ is the standard deviation of the sample returns and n is the number of observations. Using this methodology, we intend to cope with the non normality of future returns as diagnosed in the next section. Thus, our results will not be tainted by any ill-chosen distribution assumption.

The next section presents the results of our estimation strategy.

4 Estimation Results and Discussion

This section briefly summarizes the data used, and then discusses the results.

4.1 Data

The data used include plain vanilla option closing prices in € of maturity December 2008 and December 2009 traded from October 1, 2006 to November 23, 2007 on the European Climate Exchange (ECX), the most liquid trading platform for carbon derivatives with approximately 86.5% of the total exchange-based trades of allowances. Tables 1 and 2 display the number of available observations for each contract and the average volume for each strike of option prices in the dataset. Descriptive statistics regarding each contract may be found in Tables 3 and 4 (see the Appendix). For both contracts, the negative skewness indicates a distribution with an asymmetric tail extending towards more negative values. The positive excess kurtosis suggest a fat tailed empirical distribution and the presence of extreme observations. Thus, as stated by the Jarque Berra test statistics, residuals are not Gaussian which is characteristic of financial time-series. The Box Pierce statistic reveals residuals are not autocorrelated. We only consider options of moneyness included between 0.5 and 1.5 to remove unreliable observations characterized by a low volume and a low sensitivity to volatility.

We also use futures prices drawn from ECX for the same period[11]. Figures 1 and 2 show strong reversals of the futures price series depending on the time period, *i.e.* before and after the yearly compliance event. The underlying asset of the contracts are first and second period spot prices. As underlined in the previous section, due to infrequent trading of spot prices, we prefer using future prices which reflect more accurately agents' trading anticipations and hedging allowance strategies[12]. The risk free rate is the one year swap rate in € commonly used by market agents.

Over the period going from October 1, 2006 to November 23, 2007, we choose to split our dataset before and after the yearly compliance event imposed by the EC to evaluate investors' changes in anticipations. Installations need to report by the end of March their verified emissions that occurred during the preceding year. For instance, CO_2 emissions at the installation level for the calendar year 2006 were reported on March 30, 2007. Then, the information becomes publicly available when the EC officially publishes its report between the end of April and mid-May. Thus, to reflect these institutional events and to capture the state of information available to all market participants with most accuracy, Samples #1 and #2 have been split on April 30, 2007, *i.e.* at the time where the EC issued its official report for the 2006 compliance result[13]. For each contract of maturity December 2008 and December 2009, we therefore identify our two subsamples as being "October 1, 2006 - April 30, 2007" and "May 1, 2007 - November 23, 2007".

During both periods, we assume the risk-neutral and historical distributions to be sufficiently stationary to use market prices and recover both of them. This methodology only provides us with estimates of average risk-aversion on the time periods under consideration[14]. As a final assumption, we choose to work with an average time to maturity of $\tau = 1.3$ on annual basis in our dataset[15].

4.2 Estimation Results

Let us briefly summarize the estimation methodology developed in this paper. First, the risk neutral distribution is recovered from ECX option prices. Second, the historical distribution is approximated by the historical return distribution of futures allowance prices. Thus, over the entire dataset from

October 1, 2006 to November 23, 2007 we estimate the historical and risk neutral distributions. Third, as detailed in eq. (1), we infer from these probability distributions the absolute risk aversion functions for a representative investor with a 16-month investor horizon[16].

As for the historical probability distribution, Tables 5 and 6 indicate the best model is the asymmetric GARCH(1,1)-GJR to accommodate the leverage effect (see the Appendix). The result of the likelihood ratio test confirms the GARCH GJR is the best fit for the historical distribution. The chosen model is the GJR-GARCH model of Glosten et al. (1993) that we re-state below for the ease of the presentation:

$$r_t = \mu + \sigma_t \epsilon_t$$
$$\sigma_t^2 = \omega_0 + \omega_1 I_t + \alpha(r_{t-1} - \mu)^2 + \beta\sigma_{t-1}^2 + \delta \max(0, -(r_{t-1} - \mu))^2$$
$$\epsilon_t \sim N(0,1),$$

with r_t the one-day logarithmic return at time t and $I_t = 1$ if t is in Sample #2 (after the compliance result) and 0 for Sample #1 (before the compliance result). We are especially interested in the fact that ω_1 is statistically different from zero and negative: the European carbon market is characterized by more volatility before the compliance event on April, 2007 than after the compliance event. This finding is consistent with what we expected in Section 2, *i.e.* that information disclosure is due to reduce uncertainty and thus volatility on financial markets.

Compared to previous literature, our estimates strongly depart from the usual equity-based results. First, while ω_0 and α are higher than the values found in Rosenberg and Engle (2002) and Barone-Adesi et al. (2007), β is systematically lower. However, the degree of persistency of the conditional variance as measured by $(\alpha + \beta)$ is close to the values in the previously cited papers. Second, and most interestingly, λ is negative: periods of increasing market coincide with periods of higher volatility. This increasing feature is the exact opposite of the usual leverage effect found on equity markets[17]. In a context of a low environmental constraint on the carbon market, the risk associated to the option contract consists in increasing allowance prices which is the opposite of a standard commodity market[18]. Thus, beyond the information disclosure effects that led to a lower average volatility in the globally increasing Sample #2, the volatility during increasing periods has been higher than during decreasing periods. Thus, we are able to disentangle two different asymmetric volatility effects, the first being dependent on information disclosure and the second being an uncovered feature on this new market. However, as explained below when investigating implied volatility, the first effect usually dominates the other.

The rationale behind the second effect may be stated as follows. As shown in Figures 5 and 6 (see the Appendix), the implied volatilities exhibit smiles with a dramatically different slope depending on the sample considered. For both contracts December 2008 and December 2009, the smile observed in Sample #1 (displayed in blue) is skewed to the right which suggests operators anticipated a decrease of the carbon price before the release of 2006 verified emissions. For Sample #2 (displayed in red), the smile displays a leftward asymmetry which suggests operators anticipated an increase of the carbon price after the confirmation that the number of allocated allowances was higher than verified emissions at the aggregated level[19]. Between the two contracts, our analysis finds a level of implied volatility in the range of 0.8-0.9 for the second contract of maturity December 2009, which is higher than the values obtained for the first contract of maturity December 2008 comprised between 0.6-0.8. This result may be explained by the fact that the average time to maturity for option prices in the dataset is higher for the second contract compared to the first contract.

The logic at stake to comment the level of implied volatilities obtained is the following. When investors anticipate a sharp price decline, the rationale behind option pricing consists in buying puts with strikes lower than the underlying asset spot value and selling calls with higher strikes. Given the one-to-one relation between option prices and implied volatility, this results in a low implied volatility for low levels of moneyness compared to higher ones. Thus, the implied volatility is lower for levels of moneyness strictly superior to one indicating these declining trends. At every point of the support, the lower the implied volatility, the higher the probability of occurrence of the event. This relationship also explains the changes in the skewness of the risk neutral distribution.

Therefore, we uncover a dramatic shift in investors' anticipation around the 2006 compliance event. We expect this result to be of lower magnitude than during the 2005 compliance event[20]. On April 2007, the EC revealed that verified emissions were about 30 million tons or 1.45% lower than the 2006 allocation[21]. Two distinct messages are embedded in this diffusion of institutional information. First, the EC confirmed that allocated allowances were higher than the actual level of CO_2 emissions. This first element may explain why market agents were expecting a drop in the carbon price before the 2006 compliance event. Second, the EC revealed that verified emissions were lower than allocated allowances by only 1.45% for the 2006 compliance result, which corresponds to a thinner margin than for the 2005 compliance result[22]. Thus, market agents have adapted the financial risk of being exposed to a situation of allowance shortage, which may explain why they were expecting an increase in the carbon price after the 2006 compliance event. As developed in Section 2, this futures dynamics is sustained by further EC announcements to restrict allocation and to rely on auctioning during Phase II which have a positive effect on the expected allowance scarcity. As a final line of argument, the decision to maintain the EU ETS at least until 2020 may also contribute to this increasing price pattern.

The results obtained for the objective and risk neutral distributions confirm our intuitions. For the risk neutral distribution, in Figures 5 and 6, the blue line which denotes the risk neutral density for Sample #1 has a steeper curve than the red line for Sample #2, which induces more volatility. These results are therefore consistent with what we what we expected, *i.e.* to obtain lower levels of implied volatility after the EC annoucement. The results for the historical density yield the same asymmetries as for the risk neutral density of contracts December 2008 and December 2009.

Turning our attention to risk aversion, the empirical pricing kernels present noticeable shapes that underline the dramatic change in the market risk aversion. We recall that the empirical pricing kernel is defined as $\frac{\hat{q}(x)}{\hat{f}(x)}$ for each point of the support of the asset price. Figures 5 and 6 clearly illustrate this point: before the yearly compliance result (# Sample 1), market agents expect a drop in the spot price whereas after the yearly compliance result (# Sample 2) a sharp price increase is expected. From Figures 5 and 6, we may assert that the pricing kernel is countercyclical, *i.e.* it is inversely related to the current market trend. The pricing kernel is decreasing in the context of increasing markets and conversely, as pointed out by Rosenberg and Engle (2002).

These results should be compared to results obtained on equity markets, using comparable ranges of maturities and moneynesses. We use options with a longer time to maturity than Jackwerth (2000) or Rosenberg and Engle (2002) and our moneyness ranges are consequently wider than theirs. Only Barone-Adesi et al. (2007) present empirical results for a comparable range of strikes and maturities. Their estimates are ranging from 2 to 5. As shown in Figures 5 and 6, our estimates range from nearly 0 to 10. These considerably wider estimates suggest that the slope of the pricing kernel is steeper in our paper. This result applies especially for low moneynesses in Sample #2. Similar comments arise for the graphs of risk aversion where a steep slope for the pricing kernel is associated with a high level of risk aversion.

Thus, one may conclude that risk aversion on the European carbon market is higher than the values typically found on equity markets. It appears consistent with the risk premium associated to the financial exposure on such a new carbon commodity market and the necessity to adopt accurate risk management strategies.

5 Summary and Concluding Remarks

To our best knowledge, this paper constitutes the first attempt to characterize investors' risk aversion on the European carbon market based on the newly available plain vanilla option prices dataset taken from the European Climate Exchange. On the EU ETS, investors update their subjective beliefs about the distribution of allowance returns based on institutional constraints. Since the revelation of lower verified emissions than allocated allowances by 3% led to a price correction of 54% on April 2006, we test the empirical relationship between information disclosure by the European Commission and shifts in investors' risk aversion.

Based on the theoretical link that exists between the risk neutral and historical probabilities distribution on the one hand, and the risk aversion function on the other hand, we construct our estimation strategy by adapting to longer term options the existing methodology developed by Jackwerth (2000), Aït-Sahalia and Lo (2000) and Rosenberg and Engle (2002). Following Aït-Sahalia and Lo (2000), we estimate the risk neutral distribution non parametrically from option prices while the historical distribution is recovered semi parametrically from futures using an asymmetric GARCH procedure, as presented in Barone-Adesi et al. (2007) and Rosenberg and Engle (2002). Our study ranges from October 1, 2006 to November 23, 2007. Since the shifts in risk aversion are more likely to occur around yearly compliance events, we split our dataset on April 30, 2007.

Our findings may be summarized as follows. First, we find a lower level of implied volatility after the EC communication of the 2006 compliance results for contracts of maturities December 2008 and 2009. Second, we uncover the exact opposite of the usual leverage effect found on equity markets whereby periods of increasing markets coincide with periods of higher volatility. The former result emphasizes the critical role of information disclosure that was expected. The latter result reveals that the risk is associated with increasing allowance prices in a context of a low environmental constraint. Third, the pricing kernel reacts counter-cyclically. Fourth, based on a comparison for a comparable range of maturities and moneynesses, we show that risk aversion is higher on the European carbon market than on equity markets.

The increasing futures dynamics observed after the 2006 compliance result may be interpreted as an increasing awareness in terms of future tightened caps. As the EU ETS is confirmed to operate at least until 2020, investors are taking into account a medium-term carbon price signal. This trend will most likely be strenghtened by the recent EU ETS review which involves more sectors and an increasing reliance on auction mechanisms to allocate allowances as part of the global fight against climate change.

Notes

[1]One EU allowance is equal to one ton of CO_2 emitted in the atmosphere.

[2]*i.e.* the transfer of banked or borrowed allowances is allowed between Phase II and III.

[3]Available at *http : //ec.europa.eu/environment/climat/emission/reviewen.htm*. Cited February, 2008.

[4]More particularly, the aviation and petro-chemicals sectors as of 2013.

[5]Indeed, the EC is bound by law to publish the compliance result on May 15 of each year at the latest (see Directive 2003/87/CE).

[6]See for instance EC SPEECH/06/624 available at *http://europa.eu/rapid/pressReleasesAction.do?reference=SPEECH/06/624&format =HTML&aged=1&language=EN&guiLanguage=en*. Cited January 2008.

[7]Note that it is not possible to test for shifts in investors' risk aversion during the 2005 compliance event due to data limitation on the availability of option prices, but we expect lower effects on April 2007 compared to the magnitude of EUA price changes on April 2006.

[8]See Andersen and Wagener (2002) and Briere (2006).

[9]Note we rule out contracts that are not liquid such as the contract of maturity December 2007.

[10]As explained in Cont and da Fonseca (2002), this investor horizon has been identified as the best fit in our dataset. Note that this choice does not affect the robustness of the results.

[11]We do not include futures prices of maturity December 2007 in our sample since this contract has less observations and is less liquid.

[12]See Ielpo and Guegan (2008) for more details.

[13]Note the choice of the sample splitting date between end of March and end of April does not affect the stability of the results.

[14]See Rosenberg and Engle (2002) on this specific point.

[15]The choice of τ does not affect the stability of the results.

[16]The choice of this investment horizon has been discussed in the previous section.

[17]Recall that the leverage effect implies a higher level of volatility associated to decreasing prices.

[18]This logic is conform to the disconnection between first and second period allowance

prices described earlier, *i.e.* investors expect increasing allowance prices in a context of increasing allowance scarcity overtime.

[19]On April 2007 the second compliance disclosed that verified emissions were about 30 million tons or 1.45% lower than the 2006 allocation. See the EU Environment DG at *http://ec.europa.eu/environment/press/index.htm.* Cited February 2008.

[20]As stated earlier, option prices are not available to capture the magnitude of this effect.

[21]See the EU Environment DG at *http://ec.europa.eu/environment/press/index.htm.* Cited February 2008.

[22]Recall that verified emissions were lower than allocated allowances by 3% during the 2005 compliance period (Ellerman and Buchner (2008)).

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6 Appendix

	Strikes in €	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
December 2008	**Call prices**	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	156	156
	Put prices	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	156	156
	Total	570	570	570	570	570	570	570	570	570	570	570	570	570	570	570	570	312	312
	Strikes in €	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
December 2009	**Call prices**	247	247	247	247	247	247	247	247	247	247	247	247	247	247	247	156	156	156
	Put prices	247	247	247	247	247	247	247	247	247	247	247	247	247	247	247	156	156	156
	Total	494	494	494	494	494	494	494	494	494	494	494	494	494	494	494	312	312	312

Table 1: Number of available option prices
Source: European Climate Exchange

	Strikes in €	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
December 2008	**Call prices**	N.A.	N.A.	50	50	142	143	73	159	213	58	185	317	96	500	222	158	N.A.	100
	Put prices	185	80	118	172	103	58	58	200	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
	Total	185	80	168	222	246	200	132	359	213	58	185	317	96	500	222	158	N.A.	100
	Strikes in €	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
December 2009	**Call prices**	N.A.	N.A.	N.A.	N.A.	135	N.A.	50	N.A.	N.A.	366	N.A.	N.A.	N.A.	N.A.	217	N.A.	N.A.	N.A.
	Put prices	N.A.	N.A.	N.A.	15	200	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
	Total	N.A.	N.A.	N.A.	15	335	N.A.	50	N.A.	N.A.	366	N.A.	N.A.	N.A.	N.A.	217	N.A.	N.A.	N.A.

Table 2: Average volume contract for each strike
Source: European Climate Exchange

	Min	**Max**	**Average**	**Std. Dev.**	**Skewness**	**Excess Kurtosis**	**Jarque Berra test**	**Box pierce test**
Returns	-0,092	0,094	0,001	0,026	-0,404	1,667	0	0,202
Residual	-2,644	2,027	-0,002	0,91	-0,345	-0,104	0,056	0,265
Residual sample #1	-2,618	1,963	-0,026	0,872	-0,452	0,355	0,091	0,236
Residual sample #2	-2,644	2,027	0,017	0,939	-0,262	-0,347	0,306	0,865

Table 3: Descriptive statistics for December 2008 contract

	Min	**Max**	**Average**	**Std. Dev.**	**Skewness**	**Excess Kurtosis**	**Jarque Berra test**	**Box pierce test**
Returns	-0,088	0,101	0,001	0,025	-0,259	1,685	0	0,332
Residual	-2,619	2,076	-0,005	0,908	-0,306	-0,149	0,097	0,377
Residual sample #1	-2,373	2,086	-0,034	0,871	-0,337	0,172	0,292	0,467
Residual sample #2	-2,619	1,985	0,018	0,936	-0,272	-0,31	0,307	0,837

Table 4: Descriptive statistics for December 2009 contract

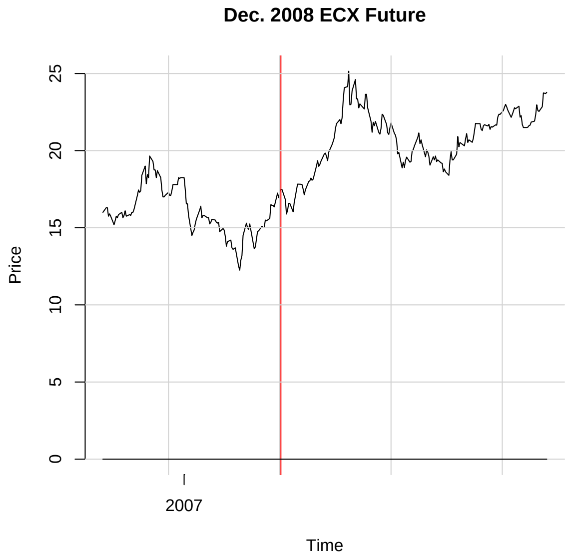

Figure 1: Historical price of the ECX future for December 2008 contract

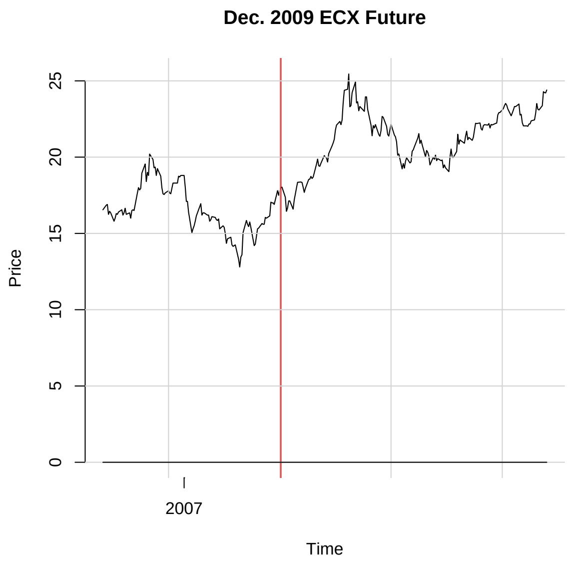

Figure 2: Historical price of the ECX future for December 2009 contract

		ω_0	ω_1	α	β	δ	μ	**Log-likelihood**
ARCH(1)	Estimate	0,079	-0,033	0,088	-	-	0,129	-666,097
	t-Stat.	6,074	-2,261	12,054	-	-	6,036	0,000
GARCH(1,1)	Estimate	0,010	-0,006	0,102	0,812	-	0,150	-659,105
	t-Stat.	3,552	-5,336	54,798	152,358	-	8,159	0,000
GJR-GARCH(1,1)	Estimate	0,009	-0,006	0,128	0,823	-0,061	0,181	-658,519
	t-Stat.	3,799	-5,859	39,471	164,938	-18,046	9,416	0,000

Table 5: Estimation of the time series models for the December 2008 contracts.

The estimated model is:

$$r_t = \mu + \sigma_t \epsilon_t$$
$$\sigma_t^2 = \omega_0 + \omega_1 I_t + \alpha(r_{t-1} - \mu)^2 + \beta\sigma_{t-1}^2 + \delta \max(0, -(r_{t-1} - \mu))^2$$
$$\epsilon_t \sim N(0,1)$$

		ω_0	ω_1	α	β	δ	μ	**Log-likelihood**
ARCH(1)	Estimate	0,081	-0,037	0,078	-	-	0,136	-659,259
	t-Stat.	5,800	-2,378	12,292	-	-	6,625	0,000
GARCH(1,1)	Estimate	0,009	-0,006	0,105	0,808	-	0,150	-652,274
	t-Stat.	3,832	-5,544	54,869	155,761	-	8,709	0,000
GJR-GARCH(1,1)	Estimate	0,009	-0,006	0,132	0,820	-0,064	0,181	-651,645
	t-Stat.	4,238	-6,250	38,876	170,801	-18,370	10,022	0,000

Table 6: Estimation of the time series models for the December 2009 contracts.

The estimated model is:

$$r_t = \mu + \sigma_t \epsilon_t$$
$$\sigma_t^2 = \omega_0 + \omega_1 I_t + \alpha(r_{t-1} - \mu)^2 + \beta\sigma_{t-1}^2 + \delta \max(0, -(r_{t-1} - \mu))^2$$
$$\epsilon_t \sim N(0,1)$$

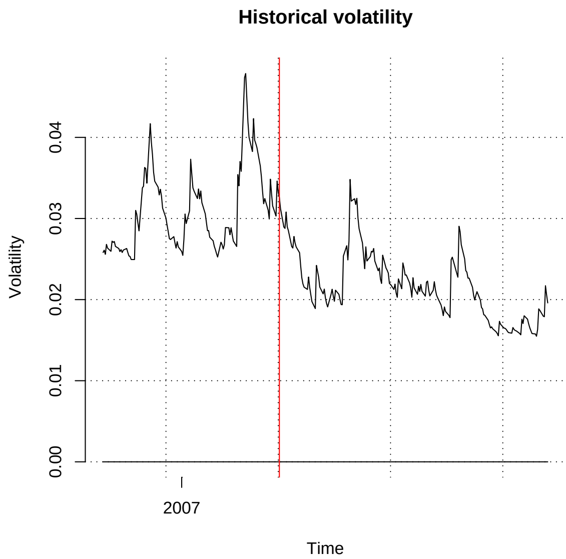

Figure 3: Historical volatility estimated from asymmetric GARCH(1,1) model for December 2008 contract

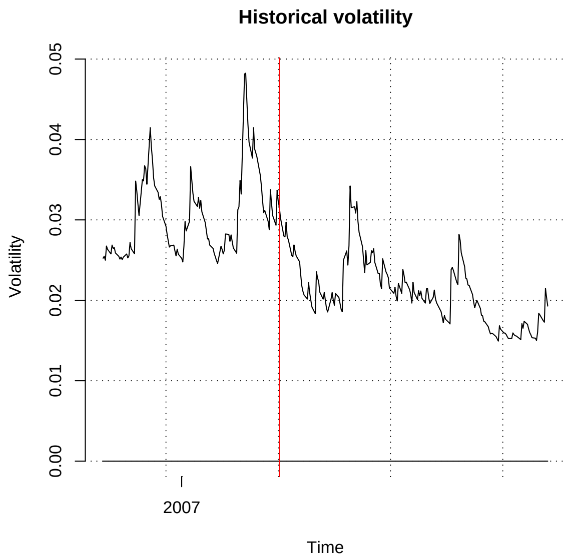

Figure 4: Historical volatility estimated from asymmetric GARCH(1,1) model for December 2009 contract

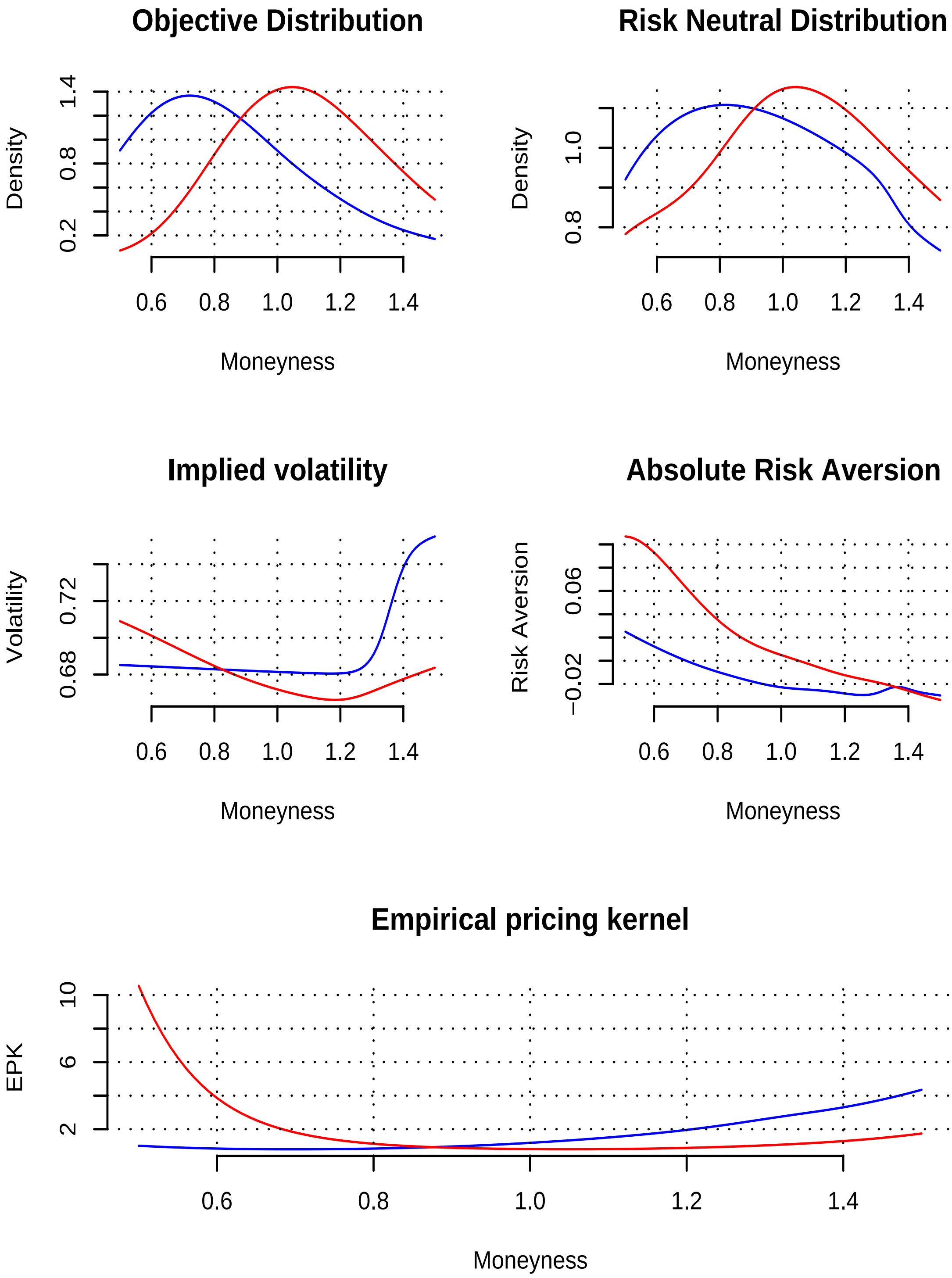

Figure 5: Estimation results for December 2008 contract with $\tau = 1.3$

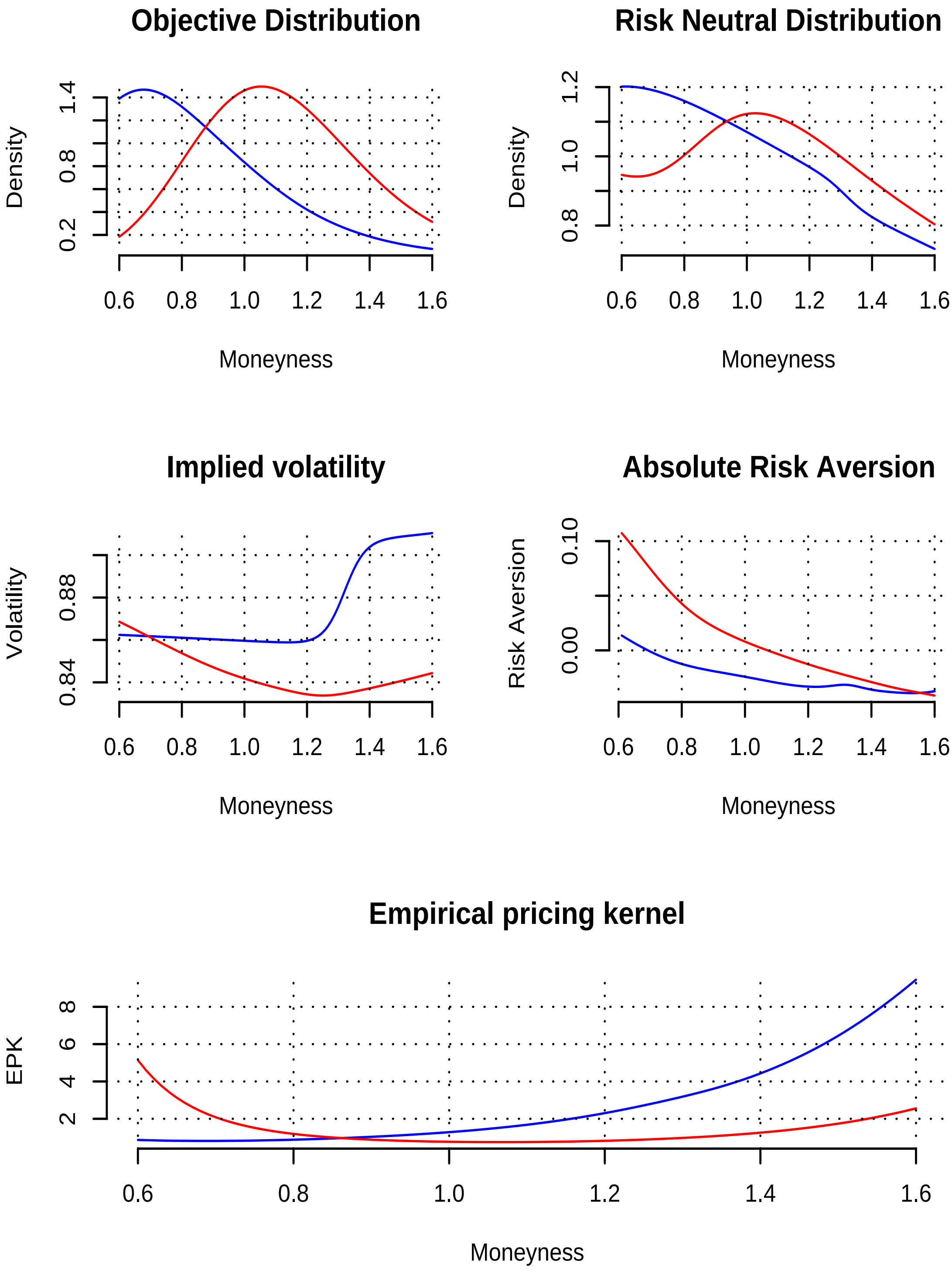

Figure 6: Estimation results for December 2009 contract with $\tau = 1.3$