The Role of Futures Markets for the Design and Performance of

Incentive Based Environmental Policy

A Study of the Sulfur Financial Instrument and European Union Allowance

by

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ABSTRACT

This dissertation outlines the role that futures markets for tradable permits can play in improving the performance of incentive based policies for environmental externalities. An extensive literature on tradable permits exists. However, to my knowledge, the role of futures contracts as an instrument for responding to permit price uncertainty has not been considered, nor has their pricing performance in this role been examined. This research provides a theoretical description of how futures can be used to manage the price uncertainty associated with permit purchases. It then evaluates if the futures contract performance for the former U.S. Sulfur Dioxide (SO_2) and the existing EU Carbon Dioxide (CO_2) futures markets are consistent with the theoretical constructs. Overall, for the short time horizons examined, futures are the best information source regarding later permit prices for both markets examined. Consistent with the theoretical model presented, this implies futures markets can be looked to as a forecast of the incremental costs of emission control. The theory illustrates that firms can then use futures to eliminate the negative effects of permit price uncertainty and restore policy compliance cost minimization. These results demonstrate that an ideal futures market for emission permits can enhance policy performance.

DEDICATION

This is dedicated to my loving wife Melissa and two daughters Madisyn and Alexis.

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CHAPTER 1

INTRODUCTION

Tradable permit systems offer policymakers an incentive based means to correct for externalities. By establishing rules for exchange and compliance, these systems allow permits to be traded in a market setting. Through assignment of property rights to permits, ownership of the right to emit a controlled pollutant is created. The permit total determines the maximum allowable amount of the pollutant. Within the rules, provisions for banking can be used to allow permits to be stored for later use. Ideally, decentralized independent agents participate in permit trading so that responsibility for controlling emissions is allocated among emitters in such a way as to equalize the incremental cost of control (Dales 1968). Beginning with Montgomery (1972) and under certainty, permit systems have been shown to reach the same cost-minimizing outcome as an effluent tax when the quantity of permits is set so that the price for each permit equals the effluent tax.

Once different types of uncertainty are introduced into the analysis, the outcome is not as clear. For instance, one line of research considers how policymaker uncertainty at the time a policy is defined can lead to different outcomes under a quantity standard versus a tax (Weitzman 1974). Depending upon whether the uncertainty is about marginal costs or marginal benefits, the findings describe how a tax or permit system may represent a second best solution. The marginal cost uncertainty and the relative slope of the cost function have been shown to be the major determinants in outcomes between a quantity standard versus a tax. Another research perspective by Schennach (2000) considers the effect of uncertainty on banking levels. This study finds that uncertainty leads to a higher level of permits being banked than in the certainty case.

The objective of this dissertation is to outline the role that a market in futures contracts for tradable permits can play to address some sources of uncertainty facing regulated firms. A futures contract is a legal agreement to either take delivery (buy) or provide delivery of (sell) a specified quantity of an underlying commodity of a particular grade (quality) at a defined future maturity date and at an agreed-upon price. The analysis develops a theoretical model that describes how permit price uncertainty affects firms' behavior and policy compliance costs in the absence of a futures market. This setting motivates the analysis to then consider whether futures contracts in permits can eliminate the effects of price uncertainty and the associated production adjustments due to a firm's risk aversion. The theoretical results used to address these questions rest on an important maintained assumption, that the futures price provides the best available information on the market-wide incremental costs of controlling the pollutant. This assumption motivates the last component to the analysis which involves evaluating the ability of futures contracts for the former U.S. Sulfur Dioxide (SO_2) and the existing EU Carbon Dioxide (CO_2) futures markets to reflect this information.

The results illustrate that permit price uncertainty is one dimension of uncertainty that can affect firms' policy compliance costs and in turn a permit system's overall performance. In the presence of a futures market for permits, this uncertainty can be eliminated if the current futures price is employed in determining the efficient level of emissions. In this situation, production is no longer affected by a firm's degree of risk aversion or changes in permit price expectations. Thus, futures allow firms to maintain supply of the marketed good at the cost minimizing level, thereby separating the output production decision from the emissions control decision.

Futures contract performance for the former U.S. Sulfur Dioxide (SO_2) and the existing EU Carbon Dioxide (CO_2) futures markets are then empirically evaluated. The analysis considers if the futures prices contain the permit compliance cost information necessary for the theoretical assumptions to hold. In comparison to spot market prices, futures are shown to reflect changes in pricing information as it occurs for both markets. In forecasting later spot permit prices, futures are then shown to encompass all of the information contained in an alternative forecast based on a theory of storage pricing model. Both the theoretical model presented and empirical information examined suggest that later permit compliance purchase decisions can be guided by futures prices. Overall, this research describes how futures contracts for permits can provide important social benefits in allocating resources, achieving pollution reductions, and mitigating permit price uncertainty. Thus, futures markets can enhance a permit system's performance.

The following chapters describe how this analysis was addressed. Chapter 2 reviews the permit literature. It discusses how permit systems perform and characterizes the types of uncertainty that have been considered in analyzing those systems. Within this literature, two important gaps exist. The first is an analysis of how firms respond to permit price uncertainty. The second is how futures contracts improve policy performance. To address the first issue, an expected utility framework is used to characterize a firm that produces both a marketable good (e.g., electricity) and the associated emissions that are regulated through the use of permits. At the time of the production decision, uncertainty exists regarding the marketable good's final price as well as the permit price. The results are then derived for a firm without access to a futures market. The risk premium is used to describe the effects that later period price uncertainty associated with the marketable good's final price and permit price have on a firm's decisions. These findings describe a measurable way to characterize a source of uncertainty that futures markets can address.

Chapters 3 and 4 describe two permit systems and their respective spot and futures markets. Chapter 3 details the U.S. SO_2 permit trading policy covered by Title IV of the 1990 Clean Air Act Amendments. Under this policy, permits regulated SO_2 emissions from the electricity sector. The rules allowed permit banking and maintained permit issuance, compliance, and trading through electronic registries over the period 1995 – 2011. Permits were traded in an active spot market during these years. In December 2004, the SFI futures contract for SO_2 permits was launched; this was the first environmental permit futures listed. By 2007, an active futures market had formed and trading continued until 2011. From 2007 to 2011, the spot permit price ranged from $1-694, and SFI1 futures prices traded from $1-720 per permit. This chapter suggests that prices were very volatile due to potential and actual policy changes which eventually led to the end of SO_2 permit policy use.

The European Union's Emissions Trading Scheme (EU ETS) for CO_2 is discussed in Chapter 4. This permit system was created to reduce CO_2 emissions as a means of limiting global temperature rise. It has continuous phases set to run through 2030 and covers regulated firms in thirty countries. To facilitate trading across countries, one homogenous CO_2 permit is used. At the start of Phase II in 2008, permits were allowed to be banked for use in subsequent years. As with the SO_2 futures, electronic registries are used for permit issuance, trading, and compliance. Chapter 4 examines CO_2 Phases II and III over the years 2008 – July 2014. During these years, EUA futures contracts for CO_2 permits were listed for trading along with several CO_2 spot markets. Over 7 billion permits were traded through futures contracts in 2013. The total number of permits issued in 2013 was 2 billion. EUA and spot prices ranged from €2-28 per permit over this period.

Chapter 5 describes the characteristics of markets for futures contracts. At any given time, futures contracts are listed for different delivery periods, ranging from one to several months in the future, thereby offering a constellation of prices. The theory of storage is used to describe the role for permit futures in a firm's decision making. Permits are required for use in the coproduction of a marketed good. Banking provisions allow them to be stored. The details of how futures for storable commodities trade, facilitate price discovery, promote large competitive markets, and smooth inventory allocation through time are then outlined. The chapter concludes by illustrating how the theory of storage can be used to describe permit spot and futures prices formation.

Chapter 6 illustrates the effects of a futures market on firm behavior. It begins by discussing the literature on futures hedging and its interaction with risk. This is followed by a hedging example. Next the presence of a futures market for permits is considered within the theoretical framework developed in Chapter 2. The marginal conditions are derived for the optimal production levels of the marketed good. In this analysis, the risk premium is used to describe firm risk and futures hedging. The findings describe how futures markets can be used in production decisions to eliminate permit price uncertainty effects.

The theoretical results assume that the futures market is ideal. An ideal futures market is one in which the price reflects the best available information, at a point in time, on the incremental cost of controlling the pollutant. Chapter 7 empirically examines the SO_2 and CO_2 futures markets for the presence of traits necessary to satisfy this information criterion. I use data on futures contracts from the U.S. SO_2 and EU CO_2 permits to evaluate pricing performance. The analysis uses three procedures. The first examines the speed with which futures prices reflect changes in permit pricing information in comparison to the spot market. The second procedure focuses on the ability of a given futures contract price to rationally forecast the eventual underlying permit price at the time of futures delivery. This analysis also determines futures' ability to encompass the information contained in an alternative forecast based on the theory of storage. The final procedure describes the futures price, spot price, and storage relationship in each market through the theory of storage. If futures prices are found to meet these information criteria, this suggests that a futures price offers a unique window into the marginal cost of compliance associated with using permits. Finally, Chapter 8 summarizes the key findings from this dissertation and identifies areas for future research.

CHAPTER 2

PERMIT POLICIES AND FIRM RESPONSE TO PRICE UNCERTAINTY

2.1 Introduction

The objective of this chapter is to evaluate how a permit system performs in the presence of price uncertainty. There is an extensive literature on tradable permits. Conventional analysis of environmental policy instruments suggests that effluent taxes and permit systems can lead to the same cost-minimizing outcome when the quantity of permits is set so that the price for each permit equals the effluent tax. Under this condition, the two instruments yield the same level of externality control measured in terms of the amount of pollutant controlled.

To my knowledge, the effects of permit price uncertainty and risk aversion have not been evaluated from a firm's perspective. This issue is important because this type of uncertainty can affect the welfare costs of implementing a permit system. By examining firm behavior subject to permit price uncertainty and risk aversion, a new perspective for the performance of these systems will be provided.

This chapter provides a theoretical description of how permit price uncertainty affects firms. An expected utility framework is used to characterize a firm that produces both a marketable good (e.g., electricity) and a pollutant that is regulated through the use of permits. At the time of the production decision, uncertainty exists regarding the marketed good's final price and the permit's final price. Risk averse firms will make output adjustments in response to this uncertainty. This theoretical analysis shows that permit price uncertainty negatively affects output of the good, raises total costs, and lowers terminal wealth.

This chapter begins by describing how firm behavior subject to uncertainty is addressed in the literature. Then permit policies are described. The literature review concludes with an overview of how the theoretical results regarding tradable permits have been evaluated. Next, a model is developed to describe a firm's behavior under permit price uncertainty.

2.2 Literature/Background

Firm Behavior

The theory of the firm under certainty assumes that a rational firm will act to maximize profits (Silberberg and Suen 1990). In a competitive market, this process is usually characterized by specifying a production function and then describing the product and factor markets. The firm's optimal output level is defined where marginal revenue equals marginal cost. The profit-maximizing choice implies cost minimization of the production factors used to produce the output quantity.

The literature has also considered situations in which a firm's decisions are made subject to uncertainty over some or all of the exogenous variables that affect decisions in the certainty case (e.g. Sandmo 1971, Chavas 2004). Conventional production adjustments in the expected utility model are used to describe firms' behavior in these situations. The expected utility hypothesis assumes that a decision maker has risk preferences represented by a utility function $U(a)$ and makes decisions to maximize expected utility $EU(a)$, where E is the expectation operator based on the subjective probability distribution of a (Chavas 2004).

The Arrow-Pratt coefficient of absolute risk aversion, r, is an index commonly used to characterize risk preferences (Arrow 1965, Pratt 1964). It is defined as the negative of the second derivative of the utility function divided by the first derivative of utility, $r \equiv -(\frac{U''}{U'})$ (Arrow 1965, Pratt 1964). Firms can be risk averse $r > 0$, risk neutral $r = 0$, or risk seeking $r < 0$ (Chavas 2004). Risk aversion affects a firm's behavior. For instance a firm with a high degree of risk aversion will require a higher expected return than a firm with a lower level of risk aversion, other things being equal.

The certainty equivalent is another method used to characterize the effects of uncertainty on firm behavior (Chavas 2004). It is widely used for asset pricing because it offers a direct way to capture expected returns, the distribution of expected returns, and risk preferences across a portfolio of assets (Cochrane 2005). The certainty equivalent measures the certain amount a firm would need to receive in order to be indifferent between receiving a risky return *a* versus a known or certain amount *R*, expressed as *[E(a)-R]* (Chavas 2004). The term *R* is the risk premium and represents the payment a firm would be willing to make to avoid risk associated with variability in the rate of return, replacing *a* by *E(a)*. The risk premium can be stated as a measure of the private cost of the risk a firm bears (Chavas 2004). In the neighborhood of the expected return, *R* is proportional to the variance of the risky return. In this setting, the Arrow-Pratt coefficient of absolute risk aversion is again used to describe the firm's risk preferences. The firm's risk preferences and utility function specification have been linked, providing the following relationships (Chavas 2004):

- Risk averse firms have $R > 0$ corresponding to $r > 0$ and $U'' < 0$
- Risk neutral firms have $R = 0$ corresponding to $r = 0$ and $U'' = 0$
- Risk seeking firms have $R < 0$ corresponding to $r < 0$ and $U'' > 0$

The theory of the firm under uncertainty was advanced by Sandmo 1971, Leland 1972, and Batra and Ullah 1974. Various aspects of this literature deal with output price uncertainty, input price uncertainty, technological uncertainty, production uncertainty, policy uncertainty, and time uncertainty (e.g. Sandmo 1971, Leland 1972, Batra and Ullah 1974, Chavas 1987, Chavas and Holt 1990, Chavas 2004). Sandmo (1971) formalized an expected utility model for examining production decisions subject to what he characterized as product market uncertainty. Product market uncertainty arises when a firm makes production decisions in one period without complete knowledge of what the output price will be when production is realized in a later period (Sandmo 1971). Such a situation may arise from a lag between when a firm decides how much to produce and when that production is realized. Chavas (2004) has shown that output price uncertainty negatively affects a firm compared to the certainty case. If a firm is risk averse, price uncertainty leads to reduced production and lower terminal wealth (Sandmo 1971, Batra and Ullah 1974, and Chavas 2004).

Permit Policy

A tradable permit system (cap and trade) can be used to control an externality[1]. Introduced by Crocker (1966), Dales (1968), and Montgomery (1972), permit systems require defining a fixed quantity of permits at a level that leads to the desired reduction in overall externality damages (Dales 1968). Montgomery (1972) was the first to formalize how a permit policy would work under conditions of certainty. In his formation, the total number of permits is set at a quantity Z. Social benefits received are a function of the

[1] Tradable permits and cap and trade are interchangeable terms of reference; the term permit will be used here.

number of permits, represented by *B(Z).* Similarly the regulated sector's cost of control is a function of the permit quantity, represented as *C(Z).* The optimal permit quantity Z^* is found that maximizes the difference between benefits received and cost incurred, expressed as $[B(Z) - C(Z)]$. The solution must satisfy $[B'(Z^*) = C'(Z^*)]$ reflecting the point where marginal benefit equal marginal cost. Under ideal conditions, the permit price equals the marginal abatement cost, represented as $q^* = C'$. If Z^* was set such that $B'(Z^*) = C'(Z^*)$, then $q* = B'(Z^*)$ by definition of Z^*. A market equilibrium permit price q^* then emerges where $q^* \equiv C'(Z^*)$. If the regulator sets the permit quantity at Z^*, the optimal solution is achieved (Montgomery 1972)[2].

When creating tradable permits, regulators must also define a set of rules that create a market in those permits (Dales 1968). The rules and assignment of property rights to permits serve to determine the type of market structure formed. Permits can be distributed as free endowments to firms, through auctions, or by a combination of the two. Under certainty the least cost solution has been found to be independent of the allocation mechanism (Montgomery 1972). After being distributed, permits can be freely traded by regulated firms and speculators alike. The system allows decentralized independent agents to participate in trading through a permit market so that responsibility for controlling emissions of a pollutant is allocated in a way that reflects the incremental cost of control (Dales 1968). Firms will take actions and behave in such a way that their

[2] The regulator could also introduce a tax equal to q^*per permit, thereby arriving at Z^* under certainty. Therefore under certainty, identical welfare solutions can be reached by either a tax or a permit (Montgomery 1972). The equivalence arises because the tax rate chosen, or permit quantity level selected, is determined at the point where marginal benefits of abatement are equal to the marginal costs of control (Montgomery 1972, Baumol and Oates 1988, Phaneuf and Requate 2014). Under certainty with regard to either the tax or the permit setting, firms are able to achieve the least cost solution.

marginal abatement costs of control equal the market-determined permit price (Dales 1968, Montgomery 1972)[3]. For instance, if a firm‘s abatement cost per unit of emissions is less than the permit price, it will sell permits and abate emissions up to the point where its marginal abatement cost equals the permit price. Conversely, if abatement cost exceeds the permit price, it will continue to produce emissions and buy permits until its marginal abatement cost equals the market permit price. Trading allows the least cost solution to be found for the set permit quantity by equating of abatement costs between different regulated sources (Montgomery 1972).

The design of permit rules can include a provision for banking. This implies permits are assets that can be stored (Schennach 2000, Phaneuf and Requate 2014). Banking allows a permit vintage to be used in compliance either in the vintage issuance year or in any subsequent year[4]. The term *vintage* is commonly used in the literature and industry to signify the year a permit was issued. For example, if a firm was issued one hundred permits in a vintage year but only needed eighty permits in compliance that year, that firm would either sell the twenty extra permits in the market or retain them as inventory for future years.

Banking effects on permit prices have been examined by Cronshaw and Kruse (1996), Rubin (1996), Kling and Rubin (1997), and Schennach (2000). Schennach's (2000) work built upon the permit pricing and banking literature in several ways. Her model considered that permit prices were 1) certain over time or 2) uncertain over time.

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[3] Conditions for this price formation are that a large competitive market exists, firms are price takers, and each firm's abatement cost information is learned/revealed.

[4] Within the policies, some auctions and other sales of distant vintage years occurred. However for this context, only permits valid for compliance in the immediate year are considered for equating firm behavior.

This specification provided a detailed analysis of how permit price assumptions and banking interact to form a price path through time. It also considers the effects of a constraint such that permits could not be borrowed from later years. In modeling uncertainty, risk neutrality was assumed. The results illustrate that uncertainty in price expectations changes both the price path and the level of banked permits. A key finding was that under price uncertainty, more permits will be banked compared to the certainty case. Further under price uncertainty, firms may bank permits even if the price rises at a rate less than the risk free rate of interest. However, the paper did not explicitly consider how benefits to storage could be measured; for other storable commodities (e.g., Pindyck 2001, Tomek 1997), storage benefits are used to analyze prices and could possibly explain the effect on banking found here.

Finally, another line of literature begins with Weitzman's (1974) seminal work and evaluates the information policymakers use in setting a tax or quantity standard policy. His paper considers how policymaker uncertainty (characterized as inadequate information about costs or benefits at inception) can influence policy outcomes. Weitzman, along with Stavins (1996), Requate (1998), Hoel and Karp (2001, 2002), Pizer (2002), Newell and Pizer (2003), and Karp and Zhang (2005), studied how these types of uncertainty would affect the choice of a price (tax) per unit versus a quantity standard. These papers evaluate the instruments in terms of the ex post welfare losses with each approach over the different sources of uncertainty. Their findings illustrate how policymakers' uncertainty may lead to a suboptimal outcome. Depending upon the degree of uncertainty and whether the uncertainty is about costs or benefits, a particular tax or permit system may represent a second best solution.

For my purposes, the permit literature has established that under certainty a permit system can be used for externality control so that a given level of control is realized at least cost. However differing sources of uncertainty, such as permit price path uncertainty, as characterized by Schennach (2000) or policymaker uncertainty described by Weitzman (1974) can lead to differences in this outcome. Therefore, motivation exists for understanding *how other types of uncertainty* may affect policy performance. Considering the rich line of literature examining output price uncertainty (e.g., Sandmo 1971, Barta and Ullah 1974, and Chavas 2004), one alternative perspective to explore is understanding whether product market price uncertainty and uncertainty in permit prices affects firm behavior and policy costs.

2.3 Context for Firm Behavior Subject to Permit Price Uncertainty

Firm Setup

This section has three objectives. First, it outlines an expected utility model that describes firm behavior in the presence of permit price uncertainty. Second, it demonstrates the negative impacts of permit price uncertainty on profits, production, total costs, and terminal wealth. Third, it expresses permit price uncertainty through a risk premium by linking the expected utility results with the certainty equivalent approach to describe firm behavior.

For the purpose of regulating production of emissions, Z, as a source of external effects, assume that a permit policy has been established and that a market for trading permits has formed[5]. In the discussion, Z is used to describe the total allowable amount of

[5] For discussion I assume that the regulated bad represents a form of emissions (SO_2 or CO_2) which allows for direct connections to the policies considered in later chapters.

emissions and *z* as an individual firm's emissions. The policy requires each firm to submit a permit, with a price of *q*, in compliance for each unit of emissions (e.g., SO_2) produced. Policy rules maintain permit issuance, accounts, and compliance through electronic registries, and they also allow for banking of permits. Because one permit is required for compliance in production of one unit of emissions, the number of permits submitted must be equal to the units of the specific type of emission allowed. The regulated firm being modeled is a multiproduct firm producing a marketable good *y* and emissions *z*. The firm is assumed to be a price taker and cannot affect the permit price or the price of good *y*.

The model represents a two-period production process. The periods could be months, quarters, or years. In the first period *t*, production decisions for both the good *y* and the emissions *z* are made. In the second period denoted as *T*, after a production lag, the final output of *y* is produced and sold. Additionally in the second period, *z* units of the pollutant are emitted which requires *z* permits for compliance. Within this setup it is assumed that once decisions are made in the first period, the quantities of the good to be produced and emissions emitted in the second period are known.

Assume that at the time production decisions are made, uncertainty exists for both the marketed good's price (e.g., electricity) and for the permit price in the second period. It follows that the firm's supply of good *y* along with its demand for *z* permits are both based on uncertain prices.

In the decision period *t*, the inputs required for the chosen production levels are purchased; input prices are considered known[6]. The firm chooses *n* inputs $x = (x_1,..., x_n)$ in the production of good *y*, and emissions *z*. The prices paid for the inputs are represented by $v = (v_1,..., v_n)$. Cost minimization for a given output means that $\sum_{i=1}^{n} v_i x_i$ can be replaced by $c(v, y)$. Assuming constant returns to scale, $y \cdot c(v)$ reflects total production cost[7].

The production technology is represented by two production functions, $y = f(x)$ and $z = g(y)$, with the *f'>0, f''<0, g'>0,* and *g''<0*. Production of good *y* generates positive revenue for the firm with a final output price per unit of *p*. Emissions *z* create costs because the existing regulation requires that each unit of *z* be matched to a permit with a unit price of *q*. From the firm's perspective, the permit price *q* multiplied by *z* is its total compliance cost.

Suppose that each firm receives a free endowment of permits from the regulator, labeled ζ. The initial policy sets the endowment quantities as annual distributions. It follows that they are considered a known quantity. The endowed permits can be used for compliance, sold, or banked as inventory. After endowments are considered, the number of permits required for regulatory compliance is $z - \zeta$, where a positive (negative) value reflects the number of permits a firm must purchase (sell from inventory).

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[6] It is assumed that enough time has elapsed for the firm to fully understand its own production costs and abatement costs. It is then assumed that the firm production processes have been learned and are known, resulting in nonrandom output.

[7] Time discounting simply adds a discount factor to input prices; for this text, it will be suppressed for clarity.

In the decision period *t*, the output period *T* unit price *p* for the good and permit price *q* are random variables. The firm's uncertain revenue is py. The uncertain permit compliance cost is $q(g(y)-\zeta)$. The good's output price *p* is represented by $p=\mu+\sigma e$, with a mean $E(p)=\mu$ where *e* is a random variable with an expected value of zero and variance of unity, and *σ* is a mean-preserving spread parameter for the distribution of *p*. The permit price in period *t* is *q*, which is assumed to be a random variable characterized by $q=\eta+\lambda\varepsilon$, with a mean $E(q)=\eta$ where ε is a random variable with an expected value of zero and variance of one, and *λ* is a mean-preserving spread parameter for the distribution of *q*. Table 2.1 provides a summary of the variables.

Table 2.1. List of Variables Defined

Variable	Description
w	wealth
y	good output, with a production function of *y=f(x),* where *f'>0* and *f''<0*
p	the good's price in period *T*, which (from the perspective of the production decision in period *t*) is assumed to be a random variable with a mean $E(p)=\mu$ in which $p=\mu+\sigma e$, where *e* is a variable random with mean zero and *σ* is a mean-preserving spread parameter for the distribution of *p*
q	the expected period *T* permit price, which is assumed to be a random variable with a mean $E(q)=\eta$, and is characterized by $q=\eta+\lambda\varepsilon$ where ε is a random variable with mean zero, and *λ* is a mean-preserving spread parameter for the distribution of *q*
z	emissions output (number of permits required), with a production function of *z=g(y),* where *g'>0* and *g''<0.*
ζ	free permit endowment
v	vector of input prices
x	input quantity, with a cost function of $\sum_{i=1}^{n} v_i x_i = c(v,y)$
E	expectation operator for the subjective probability distribution of the random variables
$U(\cdot)$	utility function, which satisfies $U' \equiv \partial U/\partial w > 0$ and $U'' \equiv \partial^2 U/\partial w^2 < 0$

Maximizing Expected Utility

The firm's uncertain revenue and compliance costs are

$$py - q(g(y) - \zeta) .$$

Its initial wealth is represented by *w*. Its terminal wealth is

$$w + py - q(z - \zeta) - C(v, y) ,$$

which is uncertain[8]. The decision maker is assumed to maximize expected utility of wealth and to have risk averse preferences represented by the utility function $U(\cdot)$

(2.1) $EU(w + py - q(z - \zeta) - C(v, y)) = EU(w + \pi)$,

where *E* is the expectations operator based on the subjective probability distributions of the random variables *p* and *q*.

The firm's production decision is described by

(2.2) $Max_{x,y,z}\{EU(w + py - q(z - \zeta) - \sum_{i=1}^{n} v_i x_i : \ y = f(x) \ \ z = g(y)\}$.

After further simplification, the production decision may be written as

(2.3) $Max_y\{EU(w + py - q(g(y) - \zeta) - c(v, y))\}$,

see (A.1). This allows the firm's decisions to be characterized entirely in terms of the good *y* output[9]. The firm's profit is $\pi = w + py - q(g(y) - \zeta) - c(v, y)$.

The first order necessary condition for optimal output *y* is

(2.4) $\dfrac{\partial EU}{\partial y}$: $E[U' \cdot (p - qg' - C')] = 0$.

The second order condition for a maximum is

(2.5) $D \equiv \dfrac{\partial^2 EU}{\partial y^2}$: $E[U'' \cdot (p - qg' - C')^2 - U' \cdot (qg'' - C'')] < 0$.

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[8] Time discounting is not considered in initial wealth for clarity; if it was, wealth would be $w(1 + r)$.

[9] Noting eq. (2.3) implies uncertainty does not affect the cost function; future research could examine cost uncertainty implications.

Equation (2.5) describes a saddle point reflecting a local maximum; it follows that the saddle point found would be in the positive production range. Additionally, because of permits' negative effect on revenue, *y = 0* is an alternative production possibility. That would be the case if, because of permit regulations, a firm is no longer profitable and shuts down.

The interaction of the uncertain good price expectation and expected utility, solved in (A.2), is $E[U'p] = Cov(U', p) + E[U']\mu$ where μ represents the good's expected unit price. The interaction of expected utility and the expectation of the uncertain permit price is $-g'E[U'q] = -g'Cov(U', q) - E[U']\eta g'$ with η the expected permit price, see (A.2). By rewriting (2.4) in terms of price expectations, the optimal choice of *y* satisfies the following condition

$$\text{(2.6)} \quad \frac{\partial EU}{\partial y}: \quad \mu = C' + \eta g' + \frac{g'Cov(U', q) - Cov(U', p)}{E(U')},$$

where the firm's marginal cost of production is $C' \equiv \partial C / \partial y$ and marginal cost of emissions compliance is $\eta g' \equiv \eta \partial g / \partial y$ with respect to *y*. Thus, production of good *y* is based on the good's expected price μ, marginal production cost of *y*, expected marginal compliance cost, and the third term. The incremental cost of compliance is represented by the expected permit price η times the number of permits associated with production of an additional unit of good *y*. It follows that in this static framework, $\eta g'$ is the firm's marginal compliance cost from producing one more unit of *y*.

The third term consists of two parts. The first is $\frac{g'Cov(U',q)}{E(U')}$ which reflects the permit's expected price relationship with utility[10]. The second is $\frac{-Cov(U',p)}{E(U')}$ which reflects the good's expected price relationship with utility. This result illustrates that the firm's production decisions for both outputs are based on and affected by uncertain prices. However at this stage, the effects of the uncertain prices are not intuitively clear. The certainty equivalent will help in explaining the effects of these uncertain prices on production of good *y*, namely through the risk premium term *R*. In this setting, the risk premium is a way to measure how product price uncertainty affects firm decisions.

The Firm's Certainty Equivalent

The certainty equivalent can be derived as an alternative characterization of the firm's response to uncertainty (Chavas 2004). It measures the private cost of risk borne by the firm using a risk premium *R*. *R* represents the amount a firm is willing to pay to avoid risk. Within this context, the firm is indifferent between receiving the risky return $(w + py - q(g(y) - \zeta) - C(v, y))$ versus the sure amount $[E(w + py - q(g(y) - \zeta) - C(v, y)) - R]$.

By combining two Taylor series expansions and by defining *r* as the Arrow-Pratt coefficient of absolute risk aversion: $r \equiv -(\frac{U''}{U'})$ (Arrow 1965 and Pratt 1964), the risk premium can be shown as

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[10] The covariance terms can also be expressed as expectations where $Cov(U', p) = E[U'\sigma e]$, and $Cov(U', -qg') = -g' E[U'\lambda\varepsilon]$ see (A.2).

(2.7) $R \approx \frac{r}{2} \cdot [\mathrm{var}(\pi)]$,

solved in (A.3), where profit variance is

$$\text{(2.8)} \quad \begin{aligned} &\mathrm{var}(\pi) = y^2 \ \mathrm{var}(p) + (g(y))^2 \ \mathrm{var}(q) + (\zeta)^2 \ \mathrm{var}(q) - 2g(y)\zeta \ \mathrm{var}(q) \\ &- 2yg(y)\,\mathrm{cov}(p,q) + 2y\zeta \ \mathrm{cov}(p,q) \end{aligned}$$

The appendix (A.3) also shows that the results hold globally. Since the variance of profits is greater than zero ($\mathrm{var}(\pi) > 0$) for any nondegenerate random variable, it can be stated that the sign of the risk premium R is always the same as the sign of r (Chavas 2004). The risk premium R can be viewed as the shadow cost of bearing risk arising from both permit price uncertainty and good y price uncertainty.

From eq. (2.7) and (2.8) the certainty equivalent expressed through (2.3) is

(2.9) $Max_y \{\mu y - \eta(g(y) - \zeta) - C(v, y) - R\}$.

The first order necessary condition is

(2.10) $\partial U / \partial y : \ \mu = C' + \eta g' + R'$

where $R' \equiv \partial R / \partial y$ is the marginal risk premium, $C' \equiv \partial C / \partial y$ is the marginal cost of production, and $\eta g' \equiv \eta \partial g / \partial y$ is the marginal compliance cost in generating one more unit of good y.

The marginal risk premium is given by the expression

$$\text{(2.11)} \quad \begin{aligned} &R' = (r)[y \, \mathrm{var}(p) + g(y) g' \, \mathrm{var}(q) - g' \zeta \ \mathrm{var}(q) \\ &- g(y)\,\mathrm{cov}(p,q) - yg'\,\mathrm{cov}(p,q) + \zeta \ \mathrm{cov}(p,q)] \end{aligned}$$

which contains terms representing the firm's aversion to risk (r), the permit price variance, the good's price variance, and the covariance between the two - all with respect to the output quantities and given the endowment of permits. The endowment terms in eq. (2.11) have signs opposite those of the emitted emissions which require permits (emissions = required permits). This is because the endowment acts as an initial inventory that essentially reduces the amount of later permits needed for compliance. Further discussion of the risk premium is continued after linkages with expected utility are highlighted.

Expected Utility and the Certainty Equivalent Connected

By comparing the certainty equivalent eq. (2.10) with expected utility eq. (2.6), it may be shown that

$$(2.12) \quad R' = \frac{g' Cov(U', q) + Cov(U', p)}{E(U')} .$$

Equation (2.12) illustrates that in producing one more unit of output *y* the covariance terms of utility may alternatively be expressed through the marginal risk premium[11].

Both expected utility and the certainty equivalent show that production decisions are based on the good's expected price μ and emission levels are based on the expected permit price η. The marginal risk premium illustrates that both of these uncertain prices interact to increase the profit variance. In turn, the profit variance interacts with a firm's risk preferences to form the marginal risk premium. Therefore, the marginal risk premium demonstrates how price risk alters the marginal costs of production and influences decisions.

The risk premium demonstrates that permit price uncertainty increases the private risk borne by firms. This risk creates policy costs to firms that lower production levels, profits, and terminal wealth. As a result, for a risk averse firm, permit policies impose

[11] This connection is well-established in the risk literature (Chavas 2004).

both incremental costs of compliance, represented by permits required for emissions, and an increase in the risk premium caused by permit price uncertainty. This suggests in the presence of permit price uncertainty, policy cost minimization is not be achieved.

2.4 Conclusion

This chapter describes how permit price uncertainty influences policy costs and decisions for a firm that must manage permit compliance. An expected utility framework is used to characterize a firm that produces both a marketable good (e.g., electricity) and the associated emissions that are regulated through the use of permits. At the time of the production decision, uncertainty exists regarding the marketable good's final price as well as the permit price. The model requires a permit to be turned in for compliance for each unit of emissions emitted. In deriving the marginal conditions, the risk premium intuition was used to describe the price uncertainty impacts through established expected utility and certainty equivalent connections.

In producing one more unit of good *y*, the incremental compliance cost is $\eta g'$. This represents the number of permits required for compliance g' times the expected permit price η. Because these emission decisions are based on the expected permit price η, permit price uncertainty alters the marginal risk premium. The marginal risk premium illustrates that permit price risk impacts decisions and increases risk borne by firms, leading to higher production costs. This effect causes lower production of the good, lower profits, and lower terminal wealth. As a result, permit policy costs include both permit compliance costs and permit price risk costs. In this setting, policy cost minimization is not achieved.

A drawback to the current model is that firms' only method of mitigating risk is to lower supply. In practice, firms have three options to mitigate permit price risk: lower production, install technology that produces fewer emissions, or hedge the risk through an alternative pricing mechanism. Therefore, motivation exists for examining other options available to firms seeking to mitigate permit compliance cost uncertainty (risk). The next two chapters describe the permit policies and their corresponding permit and futures markets; this establishes the context for assumptions and evaluation. Then Chapter Five describes why futures markets are an ideal fit for eliminating permit price uncertainty (risk) at a low cost.

CHAPTER 3

UNITED STATES SO_2 PERMIT MARKET

3.1 SO_2 Introduction

The US sulfur dioxide (SO_2) permit trading policy was initiated through Title IV of the 1990 Clean Air Act Amendments (CAAA). The policy was established to control harmful effects of pollution associated with SO_2 emissions from power plants by setting an allowable number of permits. The policy represented a new market based approach to SO_2 regulation. The SO_2 permit system is the largest permit system created in the U.S. to date. It is also the first environmental permit to have a listed futures contract. The objective of this chapter is to describe the factors that influenced SO_2 permit and futures market formation and performance.

The chapter is arranged chronologically to describe SO_2 regulations and the associated permit market. The first section discusses SO_2 emissions and prior regulations. Then the CAAA permit policy and rules are detailed. Next the sources for the data used to analyze permits are outlined. A section on permit issuance, compliance, and transactions gives context for discussions of supply, demand, and inventory levels. The spot market is then discussed. Futures are introduced, along with a detailed comparison of spot and futures volumes and prices. The chapter concludes by discussing factors that potentially influence market performance.

3.2 SO_2 Background and Prior Policy

SO_2 Background

In the U.S., SO_2 is primarily emitted as a coproduct of the burning of fossil fuels in power generation (73%) and other industrial facilities (20%) (EPA 2014). The remaining 7% is coproduced in the smelting of minerals that contain sulfur or through the burning of fuels that contain sulfur in trains, ships, and other non-road vehicles. SO_2 emissions have been found to cause damages to human health and ecosystems. Human health effects have been found to cause illness and premature mortality from heart disease, acute and chronic respiratory disease, and other lung disorders. Additionally, SO_2 is a precursor to acidic particulate matter (PM). PM contributes to acid rain formation which also detrimentally affects human health and ecosystems (EPA 2013 a).

Due to wind patterns and chemical interactions with other pollutants, concentrations of SO_2 deposits can also form nonlinear regional relationships termed “hot spots” through their spatial dispersion,. Hot spots have the potential for SO_2 accumulation to degrade some areas and populations more severely than others.

Prior to 1970, SO_2 emissions were freely discharged into the atmosphere in the course of usual business practices. Total emissions in 1970 amounted to 31.2m tons (EPA 2014). Because production of SO_2 by business firms imposes detrimental effects to others, unregulated SO_2 emissions create an externality. The Clean Air Act was passed in 1963 and amended in 1970. To correct for the externality effects imposed by the criteria air pollutants, including SO_2, part of the 1970 amendment required the Environmental Protection Agency (EPA) to develop and enforce regulations to protect the general public from exposure to airborne contaminants known to be hazardous to human health.

Currently in the U.S., ambient air quality standards are set nationally for six criteria air pollutants through powers granted in the Clean Air Act and its amendments[12]. The goal of ambient air quality standards is to protect human health within an adequate margin of safety (Burtraw and Szambelan 2009).

The amended 1970 regulations allowed the EPA to set performance standards for new and existing sources of SO_2 from power plants. In 1977, a later amendment to the Clean Air Act further changed the SO_2 performance standards. The 1977 new source performance standards established emission removal rates that required the installation of flue gas desulfurization systems, termed ”scrubbers”, even if the plants burned low sulfur coal (Burtraw and Szambelan, 2009). The 1970 and 1977 SO_2 performance standards represented a command and control approach for meeting ambient air quality standards. The policies did not achieve desired emission reductions and created incentives to keep inefficient sources in production. The regulations placed different and more stringent standards on new plants vs. existing plants, leading plants built before the 1977 amendment to have a dramatically extended life (Ellerman and Montero 2002). The SO_2 command and control policies were generally considered failures in achieving the expected emission reductions (Burtraw and Szambelan 2009).

The 1990 Clean Air Act Amendments Title IV SO_2 Permit Program

In 1990, the U.S.'s first large scale permit policy was enacted for use in controlling SO_2 emissions. The permit policy under Title IV of the 1990 CAAA created an SO_2 permit market (cap and trade) system covering emissions from the electricity

[12] The six criteria air pollutants are particle pollution (often referred to as particulate matter), ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead.

sector. The law established two phases of trading: SO_2 Phase I from 1995-2000 and SO_2 Phase II covering 2000-present[13]. The environmental objective was to achieve ambient air quality standards by lowering SO_2 pollution levels within a market based system. The CAAA SO_2 permit system was a clear shift away from the prior twenty years of command and control regulations. The policy represented an incentive based approach to SO_2 regulation with a clear focus on economic efficiency (Evans and Woodward 2013).

A focus on the electricity sector was warranted because this sector was the largest emitter of SO_2. In 2012, the U.S. produced 4,047,765m kilowatt-hours of electricity which accounted for 73% of all SO_2 emissions (EIA 2014). Within the broad economy, a focus on the electricity sector represents an upstream placement of the cap on SO_2. The sector was accustomed to complying with other regulations. Also firms had sophisticated risk management/trading departments dealing with production factors well equipped to handle trading in a newly formed permit market[14]. Thus, the sector chosen had the potential to understand regulatory requirements, trading activities, and form a permit market for pricing permits to emit SO_2.

EPA was the agency in charge of issuing permits, monitoring emissions, and enforcing compliance. The initial policy treated all emissions equally by designating one permit to be equivalent to one ton of emissions. It follows that all firm emissions were

[13] Even though the CAAA policy was passed to still be in law, all meaningful trading activity ceased by the end of 2011 (detailed later); for this research, CAAA policy will only be considered through 2011.

[14] For example, Pacific Gas and Electric and Detroit Edison are publicly traded utilities with a market capitalization of $19.75b and $12.25b respectively as of 2013. The companies own and operate coal, natural gas, wind, solar and nuclear power plants along with natural gas pipelines, underground natural gas storage and rail cars for coal transportation. Combined the two companies serve over 7m customers (Yahoo Finance 2013). As part of business operation both companies have large risk management/ trading departments that service commodity procurement, risk management, trading, and hedging. Due to the regulated nature of electricity markets in the U.S., these companies are representative of the industry as a whole.

treated equally regardless of plant geographic location. Permits were issued on January 1 of a given year. This was termed the permit vintage year. A permit vintage could be used against current emissions or banked as inventory to be used for later year compliance (i.e., permits were storable and the program created assets). For example, if a firm was issued 100 permits in a vintage year but only needed 80 for compliance, then that firm could either sell the 20 extra permits or retain them as inventory for use in future years. The actual binding market cap in any given year is equal to the number of permits issued that year plus any market inventory. The actual cap depends on the amount of electricity generated and how it was produced. Compliance was required annually for all emissions during the calendar year ending December 31. The actual compliance deadline for the year ending *N*-1, was March 1 of year N. If a firm was not in compliance, a penalty of $2000 per ton of excess emissions was assessed.

The majority of permits, 97.2%, were freely distributed yearly as endowments to the regulated firms. The endowment was based on compromises in the design of the legislation using 1980 emission levels (Chan, Stavins, Stowe and Sweeney 2012). Additionally, to allow new market participants, 2.8% of the annual permit allocation was separately auctioned yearly by EPA.

The pattern of permit distribution did not favor any specific firms (Chan et. al. 2012). Under conditions of certainty, the free allocation of permits still achieves a cost effective solution (Montgomery 1972).

The rules for the permit system also required the installation of a continuous monitoring system on all regulated plants which electronically transferred emission data to EPA. The monitoring gave EPA information on emissions emitted which it made available. In December 2001, EPA began an electronic allowance management system in which permits could be transferred online and private transactions would be recorded. The system utilized electronic registries that could be directly linked with regulated firms, firm brokerage accounts, and exchanges. The system provided a medium for trading data to be transferred to the government in a manner compatible with EPA compliance. By 2008, 99% of all private permit transactions were being registered with the system. (Note that futures delivery falls into this category.) The system served an important market role by electronically providing a transaction transfer system, a record establishment for compliance behavior, and easily accessible information, all at a low cost to market participants and the EPA[15].

By design, the CAAA provided clear institutions and rules for forming permit property rights. The policy recognized only one geographic boundary and one homogenous permit. Further, the law provided for only a single regulatory agency, the EPA, to issue permits, enforce compliance, monitor emissions, and disseminate information. This system envisioned the federal government playing a minimal role at a low cost. In fact, through electronic permit issuance, trading, and compliance, transparent and standardized monitoring, EPA information dissemination, and clear rules, there was broad consensus that the permit market operated fairly with a virtually perfect compliance record (Burtraw and Szambelan 2009, Schmalensee and Stavins 2012). Thus, the initial CAAA rules and property rights provided for one homogenous permit,

[15] However, for research purposes the system does not report transaction price data or a breakout of transactions by source.

one governing law, one regulator, and one regulated sector as the boundaries for permit market formation.

3.3 Data

Three primary types of data are discussed in the following sections and later used in empirical testing.

1) Actual SO_2 permit issuance, compliance, inventory levels, and reported transactions. The data was collected from the EPA website, allowance management system, and EPA reports (e.g., EPA 2010, EPA 2013).

2) SO_2 spot market prices and volume. The Cantor SO_2 over the counter (OTC) market, listed through BGC Environmental Brokerage Services (formerly CantorCO2e Brokerage), was the primary SO_2 spot market[16]. Daily spot prices from July 2003 - October 2011 and daily transaction volume from 2003-2009 were gathered for the Cantor SO_2 OTC directly from BGC (2012).

3) SO_2 futures. The Sulfur Financial Instrument (SFI) futures contract served as the primary SO_2 futures contract. SFI daily prices, volume, contract symbols, and open interest for all monthly contracts were gathered from December 2004 – December 2011 as sourced from Bloomberg (2013, 2014).

The spot market is a term used to describe the physical permit market; the spot price is the term used to describe permit prices. The OTC market is a spot market listed by a specific brokerage firm (here it was listed by BGC Environmental Brokerage Services). The term OTC price is the term used to describe spot permit prices of this market. The term spot and OTC are interchangeable terms of reference to permit prices.

[16] Index and OTC are interchangeable terms used in the literature; here, OTC will be used.

Generally for this research, spot is used commonly in reference to general or theoretical discussions. OTC is used when referencing the specific markets; however at times either is appropriate.

3.4 EPA Permit Issuance, Compliance, and Transactions

A total of 160.55m permits issued from 1995-2012[17]. Permits began to actively trade in 1994 with Phase I covered the 263 largest and dirtiest electricity generators with a capacity over 100mw[e], which produced 9.4m tons of SO_2 in 1980. Phase I permits issued in 1995 were capped at 8.7m and reduced to 7m by 1999. Table 3.1 displays the yearly numbers of SO_2 permits allocated, turned in, banked and traded over Phases I and II. During Phase I, 38.1m permits were issued and 26.4m were used in compliance. The result was a banked supply of 11.7m permits at the start of Phase II. The excess Phase I permit supply could be carried over as inventory into Phase II on a one for one basis.

Table 3.1 SO_2 Phase II Permits Issued, Firm Emissions, and Banked 2000 - 2010

Year	Permits issued	Year bank	Total bank	Firm emissions
2000	10	-1.2	10.5	11.2
2001	9.6	-1	9.5	10.6
2002	9.5	-0.7	8.8	10.2
2003	9.5	-1.1	7.7	10.6
2004	9.5	-0.8	6.9	10.3
2005	9.5	-0.7	6.2	10.2
2006	9.5	0.1	6.3	9.4
2007	9.5	0.6	6.9	8.9
2008	9.5	1.9	8.8	7.6
2009	9.5	3.8	12.6	5.7
2010	8.95	3.85	16.45	5.1
Totals	142.65	16.45	139.55	211.9

Note: All numbers are in millions; baseline emissions in 1980 were 17.3m tons
Source: Own calculations from EPA reports

[17] The EPA website, allowance management system and reports were accessed for permit data (EPA 2010, EPA 2013).

The corresponding annual electricity production generated over all policy years by source and in total is displayed in Table 3.2. Total electricity production in 1980, the CAAA baseline year, was 2,289,600m kilowatt-hours (EIA 2014). In 1995, 2000, 2005, and 2010, total electricity production was 3,353,487m, 3,802,105m, 4,055,423m, and 4,125,060m kilowatt-hours respectively. Electricity production peaked in 2008 and dipped slightly in the years following due to the U.S.'s financial crisis and corresponding economic slowdown. However by 2013, total electricity production had approximately reached prior levels. Overall the table shows that total electricity generation gradually increased over the policy years spanning 1995 – 2013.

Table 3.2 U.S. Electricity Generation: (All Sectors)

Year	Coal	Nat. Gas	Nuclear	Hydro	Solar	Wind	Other	Total
1950	154.5	44.6	0.0	100.9	-	-	34.1	334.1
1960	403.1	158.0	0.5	149.4	-	-	48.2	759.2
1970	704.4	372.9	21.8	251.0	-	-	185.1	1,535.1
1980	1,161.6	346.2	251.1	279.2	-	-	251.5	2,289.6
1990	1,594.0	372.8	576.9	292.9	0.4	2.8	198.1	3,037.8
1995	1,709.4	496.1	673.4	310.8	0.5	3.2	158.7	3,353.5
1996	1,795.2	455.1	674.7	347.2	0.5	3.2	167.8	3,444.2
1997	1,845.0	479.4	628.6	356.5	0.5	3.3	179.3	3,492.2
1998	1,873.5	531.3	673.7	323.3	0.5	3.0	215.9	3,620.3
1999	1,881.1	556.4	728.3	319.5	0.5	4.5	206.6	3,694.8
2000	1,966.3	601.0	753.9	275.6	0.5	5.6	200.0	3,802.1
2001	1,904.0	639.1	768.8	217.0	0.5	6.7	197.4	3,736.6
2002	1,933.1	691.0	780.1	264.3	0.6	10.4	174.2	3,858.5
2003	1,973.7	649.9	763.7	275.8	0.5	11.2	202.8	3,883.2
2004	1,978.3	710.1	788.5	268.4	0.6	14.1	204.7	3,970.6
2005	2,012.9	761.0	782.0	270.3	0.6	17.8	204.7	4,055.4
2006	1,990.5	816.4	787.2	289.2	0.5	26.6	147.8	4,064.7
2007	2,016.5	896.6	806.4	247.5	0.6	34.4	149.4	4,156.7
2008	1,985.8	883.0	806.2	254.8	0.9	55.4	127.8	4,119.4
2009	1,755.9	921.0	798.9	273.4	0.9	73.9	119.1	3,950.3
2010	1,847.3	987.7	807.0	260.2	1.2	94.7	119.7	4,125.1

Table 3.2 (Cont'd) U.S. Electricity Generation: (All Sectors)

Year	Coal	Nat. Gas	Nuclear	Hydro	Solar	Wind	Other	Total
2011	1,733.4	1,013.7	790.2	319.4	1.8	120.2	113.7	4,100.1
2012	1,514.0	1,225.9	769.3	276.2	4.3	140.8	108.3	4,047.8
2013	1,586.0	1,113.7	789.0	269.1	9.3	167.7	115.5	4,058.2

Notes: Electricity in billion kilowatt-hours. Other sources include petroleum, other gases, wood, waste, geothermal.
Source: Own calculations from IEA reports

Phase II began in 2000 with coverage of 3,572 electricity generating units. This included all of the original Phase I firms, and additionally covered all fossil fuel steam boilers with a rated generation capacity of over 25 mw[e]. Because of the rules covering boilers, one plant could have multiple regulated boilers. By Phase II the program covered virtually all electric plants in the U.S. Phase II baseline SO_2 emissions in 1980 were 26.7m tons. At the beginning of Phase II, emissions were capped at 10m tons with the cap reduced to 8.95m tons by 2010 (Table 3.1). The permit reduction was written as part of the initial law (i.e., the cap change was a known rule).

During the first six years of Phase II, 2000 – 2005, 57.6m permits were issued and 63.1m were used in compliance, resulting in an inventory drawdown of 5.5m permits. Then from 2006 – 2010, 46.95m permits were issued and only 36.7m permits used for compliance, resulting in the banked supply growing to 16.45m permits by the end of 2010 (Table 3.1). By 2010, total emissions were only 5.1m tons per year, representing a decline of 70% from 1980. Over the same time period, total electricity produced rose from 2,289,600m to 4,125,060m kilowatt-hours, representing an 80% increase.

SO_2 Stocks- to-Use Ratio

The stocks-to use-ratio can be used to explain the permit supply, demand, and inventory conditions[18]. This ratio measures how long the current permit supply will last, based on current demand. The ratio only considers permits valid for compliance within a vintage year (i.e., no borrowing of permits is allowed). For SO_2 permits, the ratio can be measured with a high degree of accuracy because of EPA issuance, monitoring, and compliance real time information. The permit stocks-to-use ratio is defined as

$$(3.1) \quad \frac{(issued\ permits\ in\ year_t) + (beginning\ month_t\ inventory) - (month_t\ emissions)}{year_t\ total\ emissions}$$

The permit compliance total for emitted emissions compliances is based on year *t* data. Yearly emissions totals are used instead of monthly or forecasted values. The large permit supply over the evaluation period implies that small differences in adjustments used to compute the ratio, accounting for seasonality or other factors, would not alter the implications of the basic comparison.

December and January stocks-to-use ratios, permits issued, and compliances turned in from 2000 – 2011 are reported in Table 3.3. December values are discussed because these end of year values provide the lowest supply level and represent a worst case scenario. January is reported because that is the month in which the annually issued permit supply enters the market. The December 2000 stocks-to-use ratio was 1.02 years, implying that in December 2000 there were enough permits held as inventory to meet current demand levels for slightly more than one full year. The initially high ratio is a direct result of the large permit supply carried over from Phase I. From 2000, the ratio

[18] The ratio is used and forecasted extensively in other commodity markets such as crude oil and corn.

gradually declined each year until 2005 when it reached 0.6 years, implying permits held as inventory were sufficient to meet current demand for about seven months. The decline in this ratio is a result of compliance needs being greater than the yearly issued supply.

Table 3.3 SO_2 Permit Stocks-to-Use Ratios 2005 - 2011

Date	Stocks: use (month)	Stocks: use (year)	Total supply	Issued permits	Permits used
1/1/2000	23.250	1.938	21.700	10	-
12/1/2000	12.250	1.021	11.433	-	11.2
1/1/2001	22.755	1.896	20.100	9.6	-
12/1/2001	11.755	0.980	10.383	-	10.6
1/1/2002	22.353	1.863	19.000	9.5	-
12/1/2002	11.353	0.946	9.650	-	10.2
1/1/2003	20.717	1.726	18.300	9.5	-
12/1/2003	9.717	0.810	8.583	-	10.6
1/1/2004	20.039	1.670	17.200	9.5	-
12/1/2004	9.039	0.753	7.758	-	10.3
1/3/2005	18.294	1.525	15.550	9.5	-
12/1/2005	7.294	0.608	6.200	-	10.2
1/3/2006	19.043	1.587	14.917	9.5	-
12/1/2006	8.043	0.670	6.300	-	9.4
1/2/2007	20.303	1.692	15.058	9.5	-
12/3/2007	9.303	0.775	6.900	-	8.9
1/2/2008	24.895	2.075	15.767	9.5	-
12/1/2008	13.895	1.158	8.800	-	7.6
1/2/2009	37.526	3.127	17.825	9.5	-
12/1/2009	26.526	2.211	12.600	-	5.7
1/4/2010	49.706	4.142	21.125	8.95	-
12/1/2010	38.706	3.225	16.450	-	5.1
1/3/2011	66.733	5.561	25.025	8.95	-
12/1/2011	55.733	4.644	20.900	-	4.5

Notes: Permits are in millions; Stocks: use ratio computes the amount of time the current supply of permits will last based on the current emission rates
Source: Own calculations from EPA reports

The December stocks-to-use ratios from 2005 thru 2011 were 0.60, 0.67, 0.78, 1.16, 2.21, 3.22, and 4.64 respectively. During these years, the December ratio, the lowest yearly point, was always greater than a six month supply. Further, the ratio climbed drastically over time with over one year's excess supply from 2008 on. This large increase in stocks was caused by a 50% decrease in firm emissions; emissions fell from 10.2m in 2005 to 5.1m in 2010. Because of the rapid decline in emissions and growing stocks, the 2010 ratio represented over three years of available permits at the then-current emissions rate. However, total electricity generated actually rose slightly from 4,055,423m in 2005 to 4,125,060m kilowatt-hours in 2010 (EIA 2014). Because yearly issuance remained approximately constant as did electricity production, firms clearly reduced the level of emissions per kilowatt-hour of electricity output[19]. The result was that the market had an abundant supply of permits.

By comparison, over the last twenty years, the year ending stocks-to-use ratio for corn just before new crop harvest, its lowest yearly point, has only been above 0.30 (just over a three month supply) once. Further, the ending corn stocks-to-use ratio fell below 0.10 (1.2 months' supply) five times.

Some overall judgements arise from Tables 3.1, 3.2, and 3.3, along with the SO_2 market discussion that can describe the permit market supply. Over the years from 1995 – 2010, total electricity production increased 80%. A bank of 11.7m permits from Phase I was available at the start of Phase II. During Phase II, the annual number of permits issued declined gradually from 10m down to 8.95m. In the early Phase II years (2000 - 2005), total emissions outpaced issued permits, forcing a drawing down of the permit bank. Thereafter, firm emissions rapidly declined from 10.2m tons in 2005 to 5.1m by

[19] The U.S. financial crisis and economic slowdown contributed to a slight dip in electricity production in 2009 and then increased back to approximately constant levels with 2008 production from 2010 – 2013. However as the tables illustrate, the lowering in emissions emitted per KWH from 1995 to 2010 generally can be attributed to the permit supply increasing.

2010. These factors resulted in an adequate permit supply over 2000 – 2005, due to the carryover of the large Phase I inventory. Then from 2005 – 2011, the rapid decline in firm emissions drove excess supply. Based on the original CAAA rules and the annual supply, clear supply trends were formed. Intuitively permit prices should exhibit different pricing patterns between the two periods -- 2000 – 2005 and 2005 – 2010.

EPA SO_2 Transactions

The EPA recorded permit transfers in two broad categories[20]. The first is between economically related firms in the form of permit transfers between utility plants that have the same ownership. For example, Pacific Gas and Electric (PG&E) owns several utility plants in various states (see Table 3.4). Each plant is issued its own permit endowment from the EPA. However, PG&E would be the owner of record for all the permits its plants were issued. If a PG&E plant in Florida was issued 100 permits and used 80 for compliance, a surplus (long position) of 20 permits would exist. Simultaneously, if a PG&E plant in California was issued 200 permits, but needed 220 permits for yearly compliance, a resulting deficit (short position) of 20 permits would exist. To meet compliance at both plants, PG&E would transfer 20 permits from the Florida plant to the California plant. Compliance at both plants would then be met through an economically related transfer, as defined by the EPA. Table 3.4 illustrates this example. When offsetting positions exist between economically related firms, as in the example, outside transactions for offsetting position are not typically necessary. Thus, economically related transactions imply that no futures market activity would be used for

[20] For consistency and comparisons, EPA's definitions are followed for use of their data, noting that the terminology and definitions differ from other commodity trading terminology and reporting.

trading/hedging purposes. This is similar to many commodity markets; for example, Exxon (Cargill) commonly trades crude oil (corn) between plants for facilitating individual plant supply and demand needs.

The second EPA category is economically unrelated transfers between firms with no ownership relationship. Economically unrelated trades necessitate exchange through private negotiation, brokerage houses, OTC markets, or futures markets. For example, if a PG&E plant in Florida has to purchase 100 permits from a Detroit Edison-owned plant in Michigan, the transaction would be termed an economically unrelated transfer of permits by EPA (Table 3.4).

Table 3.4 EPA Permit Transfer Categories Example: Pacific Gas and Electric Utility Plants

	Issued	Emissions	Permits Required	Net	Transaction	Compliance
Related example:						
Florida	100	80	80	20	-20	80
California	200	220	220	-20	20	220
Unrelated example:						
Florida	100	80	80	20	-20	80
Michigan	200	220	220	-20	20	220

Total SO_2 transactions for both EPA categories through 2009 were 392.2m permits. Of the total 121.8m (31.1%) permits were traded in economically unrelated transactions. The remaining 270.4m (69.9%) traded permits were between economically related entities. Table 3.5 provides a listing of the EPA transactions from 1995 – 2009. In the first two years of trading, 1995-1996, only about 10% of the 28.7m permits traded were between economically unrelated firms. By 1998, economically unrelated trades had increased to 9.5m permits accounting for 41% of the year's total trades. At the beginning of Phase II (2000), 12.7m permits (35.9%) were traded between economically unrelated firms. Over the available Phase II data, the average yearly volume of economically unrelated trades was 9.1m permits, accounting for 48% of all trades.

The 9.1m yearly average trading volume between economically unrelated firms was about equal to average permit compliance of 9.47m over this time[21]. As highlighted by Ellerman (2002), this approximate correspondence is consistent with firms taking advantage of the cost savings that can be realized by re-allocating the responsibility for reducing emissions to the least cost abating units through trading.

Table 3.5 SO_2 Permits Traded 1994-2010

Year	Permits issued	Permits used	Economically related trades	Economically unrelated trades	Percent economically unrelated	Total trades
1994	-	-	8.3	0.9	9.78%	9.2
1995	8.7	5.3	14.8	1.9	11.38%	16.7
1996	8.3	5.4	3.8	4.4	53.66%	8.2
1997	7.1	5.5	7.3	7.9	51.97%	15.2
1998	7	5.3	4	9.5	70.37%	13.5
1999	7	4.9	12.5	6.2	33.16%	18.7
2000	10	11.2	12.3	12.7	50.80%	25
2001	9.6	10.6	9.9	12.6	56.00%	22.5
2002	9.5	10.2	9.8	11.6	54.21%	21.4
2003	9.5	10.6	8.4	8.1	49.09%	16.5
2004	9.5	10.3	7.8	7.5	49.02%	15.3
2005	9.5	10.2	9.9	10	50.25%	19.9
2006	9.5	9.4	12.9	9.5	42.41%	22.4
2007	9.5	8.9	7.8	9.1	53.85%	16.9
2008	9.5	7.6	8	5.9	42.45%	13.9
2009	9.5	5.7	11.1	4	26.49%	15.1
2010	8.95	5.1	na	na	na	na
Totals	142.65	126.2	148.6	121.8	45.04%	270.4

Note: All numbers are in millions. Source: Compilation of EPA 2010 and EPA 2013 documents

[21] Of the EPA trade total, there is no way to determine how many trades correspond with futures delivery.

3.5 SO_2 Permit Spot and Futures Markets

SO_2 Spot Market

Permit pricing mechanisms used from 1995 – 2004 were over the counter markets (OTCs), government auctions, forward contracts, and private negotiations. Private negotiations could be for spot (immediate) or forward delivery depending on the parties' agreed-upon terms. Government auctions were conducted yearly and accounted for 2.8% of the vintage issuance. Market participants consisted of regulated firms, financial intermediaries, brokerage houses, and speculators.

The Cantor SO_2 OTC was the primary spot pricing point for the market[22]. The Cantor SO_2 OTC was a financial product of BGC Environmental Brokerage Services (formerly CantorCO2e), a brokerage house that specializes in environmental trading services[23]. Spot trading was also conducted on other OTC markets operated by the Chicago Climate Exchange (CCX), Emissions Exchange (EX) and Fieldston (EATX) with limited degrees of success.

Figure 3.1 and Table 3.6 provide a graph and table description of the Cantor SO_2 spot prices and volume from 2003 - 2011. The Cantor OTC had a yearly average volume of 0.7m permits from 2003 – 2009, with a peak in 2004 of 1.5m permits. Permit prices during Phase II, from 2000 - 2011, ranged from $1 to $1626/ton. All discussed prices for permits are listed in $/ton and hereafter the "per ton" will be implied. Prices began increasing in 2003 from approximately $200 and reached a peak of $1626 in 2005. This

[22] This is supported by the Cantor OTC being the EPA's price reported for its publications (e.g. EPA 2010).
[23] In August 2011, the business of CantorCO2e, L.P., was acquired by BGC Partners, L.P. and became BGC Environmental Brokerage Services, L.P. For these purposes, the purchase did not alter the Cantor SO_2 OTC.

was followed by a sharp decline to an average price of $528 in 2008. Prices continued to decline, ultimately collapsing to $1 by October 2011. The price range and volatility exhibited must be viewed in consideration of outside events (i.e., factors not envisioned in the initial rules) that ultimately led to the market collapse. The policy event section outlines in greater detail the potential role for rule changes and other events to influence the price series movement and market collapse. For the present purpose, all economically meaningful CAAA SO_2 permit trading ceased by October 2011.

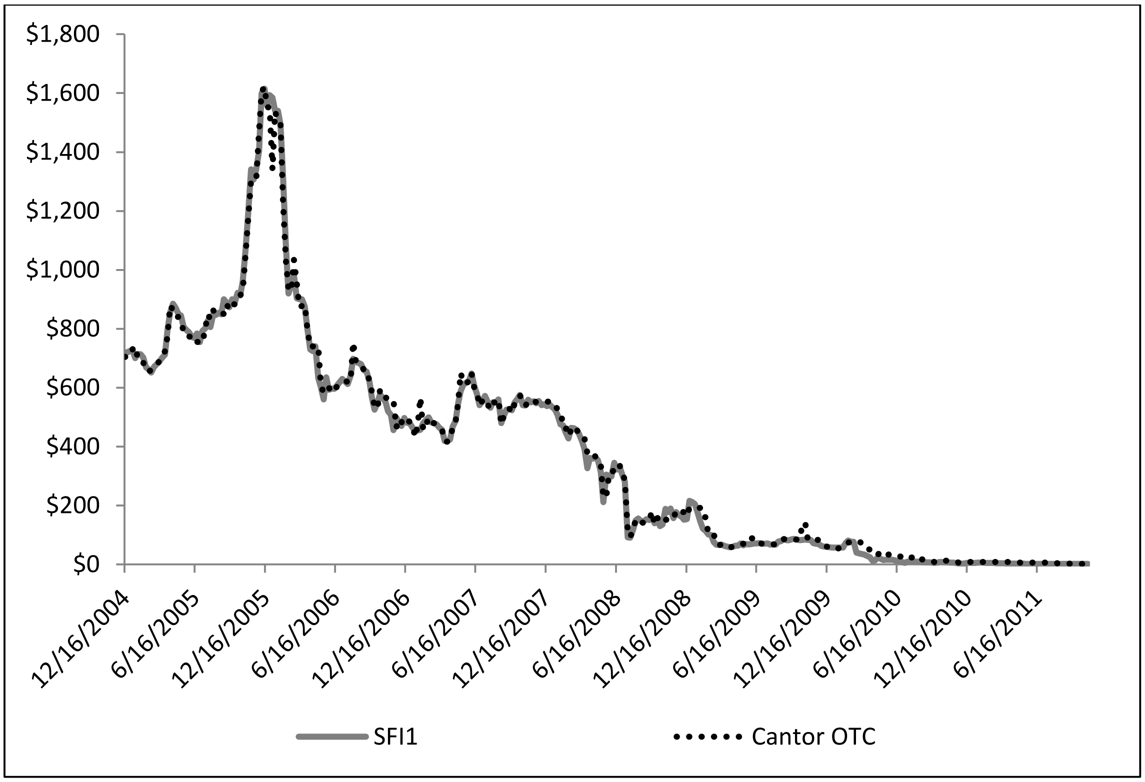

Figure 3.1 SO_2 Spot and SFI Futures Prices (2004 - 2011)

Table 3.6 Cantor SO_2 OTC Prices and Volume 2003-2011

Year	Mean price	Min price	Max price	Volume
2003	$192	$174	$221	699,443
2004	$437	$215	$722	1,565,463
2005	$901	$640	$1,626	1,019,965
2006	$743	$465	$1,583	390,104
2007	$528	$395	$694	994,413
2008	$281	$93	$552	319,482
2009	$89	$56	$192	295,864
2010	$33	$5	$233	na
2011	$6	$2	$9	na
Totals	$377	$2	$1,626	5,284,734

Notes: Prices and volume data were from separate data.
Source: Own calculations from BGC 2012 data

SO_2 Futures Market

In December 2004, the Chicago Climate Exchange launched the Sulfur Financial Instrument (SFI) futures contract, whose underlying commodity was a SO_2 permit[24]. SFI futures marked an important financial innovation because SO_2 permits could now be priced over different time horizons through standardized exchange-traded futures. Policy created permits for SO_2 emission rights were now traded side by side with other commodity futures. To my knowledge, the SFI futures contract represented the first environmental policy permit ever listed as an exchange traded futures.

Additionally in August 2005, the New York Mercantile Exchange introduced the sulfur dioxide futures contract (RS) through CME's electronic platform. However, the RS contract never achieved adequate liquidity and the RS futures failed by 2008.

[24] For futures market definitions, market details, and price formation see Chapter Five.

A factor influencing general futures expansion during the 2000's was electronic trading[25]. Electronic trading offers a substantial opportunity for exchanges to lower exchange costs. Further, electronic futures offer exchanges a low cost means of introducing new contracts in markets where futures did not previously exist. Electronic futures also offer participants unlimited trading access, price transparency, and lower transaction costs which can generate trading volume for futures that would not otherwise succeed. Thus in the launch of SFI futures, electronic trading enhanced the contracts potential to be successful.

In 2003, the Intercontinental Exchange (ICE) partnered with the Chicago Climate Exchange to host its electronic marketplaces. As one of the world's largest exchanges, ICE offered secure and fully developed electronic trading platforms. The electronic trading changes and partnership influenced the December 2004 SFI launch. It also was the lead-in to ICE's purchase of the Chicago Climate Exchange in April 2010[26]. ICE bought the Chicago Climate Exchange through a purchase of its parent company Climate Exchange PLC for $622m. With ICE's purchase, the exchange was officially closed and all products transferred to ICE on February 28, 2011. For current research purposes, ICE's purchase did not alter the SFI contracts of interest. ICE will be the referenced exchange company hereafter.

[25] A brief discussion of electronic trading is needed for context of the timing of the contract launch. The Chicago Mercantile Exchange (CME), the world's largest futures exchange, launched its first electronic contract in 1992 with 70% of its volume coming from electronic trading by 2003. Conversely, the Chicago Board of Trade (CBOT), the world's oldest futures exchange, did not introduce electronic trading to its agriculture products until 2006.

[26] Interestingly, Climate Exchange PLC also owned the European Climate Exchange (ECX) which listed the European Union Allowance (EUA) futures studied for the CO_2 markets now also owned by ICE.

The SFI futures contract specifications were for delivery of 25 U.S. EPA SO_2 allowances under Title IV of the CAAA at maturity. Appendix B provides an SFI futures contract specification sheet for 2010 futures from ICE. Upon maturity, the buyer (owner) of one SFI contract would take possession of 25 SO_2 permits. Similarly at delivery, the seller must provide 25 SO_2 permits. Therefore at the maturity date, SFI futures became an electronic supply transfer of SO_2 permits. Because EPA used electronic registries for SO_2 permit issuance, accounts, and compliance there were no additional transaction costs associated with futures delivery of permits[27].

Beginning in December 2004, SFI contracts were listed quarterly for March, June, September, and December maturities until March 2006. Then from March 2006 onward, an SFI contract was listed for each month three years out. Each calendar year is considered a vintage year with contracts created to match the spot permit cycle (i.e., SO_2 permits annual vintage issuance). December SFI contracts were listed for up to five years out. It is common to list only one contract for distant time horizons because trading volume typically decreases. The December contract was selected because as the compliance calendar year end, its yearly contract was the most actively traded [28]. Appendix B provides a list of all the SFI contracts traded from December 2004 - March 2012. Within the futures listing the symbols are expressed by SFI(letter)(#) where SFI stands for the contract root (Sulfur Financial Instrument), the letter is maturity month, and the # is maturity year[29]. Contract maturity is the futures last trading day The SFI was

[27] Chapter Six details how futures turn into physical permits and discusses potential price differences.
[28] For example, corn and soybeans follow a similar pattern with the harvest month contract as the futures selected for distant year listing.
[29] For SFI and the majority of futures contracts the following letters correspond to these months F – January, G – February, H – March, J – April, K – May, M – June, N – July, Q – August, U – September, V – October, X – November, and Z – December.

officially delisted in March 2012 as a result of the underlying CAAA permit market collapse.

The maturity date was also the last trading day of a particular contract. This date was set three business days prior to the last business day of the expiration month (CCX, 2012)[30]. An example of a contract listing is the SFI December 2009 contract (SFIZ09) which represents the December 2009 vintage year SFI futures contract. Its last trading day was Monday, December 28, 2009. The contract transaction entry or exit fee as of 2006 was $2.00 per contract for non-members and $1.60 for members[31]. The transaction fee for nonmembers of one SFI contract in 2006 represented 0.0114% of the contract's total permit value. This is consistent with the assertion that futures provide a low cost means for exchange.

The one month ahead (front month) contract is identified by the contract month about to expire. One month ahead futures present the closest comparison to the spot price. For example, on July 1, 2009, the one month futures contract represented the July 2009 SFI contract (SFIN9) which matured on July 28, 2009. Then on July 29, 2009, the one month contract rolled over and became the August 2009 SFI contract (SFIQ9) which matured on August 26, 2009. The one month series is denoted hereafter as SFI1.

For consistent time horizon analysis, daily rolling contract series were constructed to represent the one month ahead (SFI1), two months ahead (SFI2), three months ahead (SFI2),…, twelve months (SFI12) ahead futures. The rolling series structure creates

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[30] The SFI contracts' first notice day for performance is also three business days prior to the last business day of the expiration month (Chicago Climate Exchange 2012).

[31] In futures trading terminology, entry or exit of a position is termed a side. A full contract fee is the complete round turn for entry and exit of a position.

observations over time that represent identical time horizons for forecasts[32]. The futures SFI1-12 month series represents what the market expects spot prices to be at the different time periods. As discussed in Chapter Six these provide the basis for estimating what expected marginal compliance costs will be at the time of the contract maturity. An example of how the SFI monthly horizons works is presented in Table 3.7. The table illustrates the SFI1 -5 month horizons. On July 1, 2007, the SFI futures had contracts listed with the following maturity and prices: July 2007-SFI1 $542; August 2007 SFI2 $544; September 2007 SFI3 $546; October 2007 SFI4 $548; November 2007 SFI5 $550. This means that on July 1, 2006, the SFI2 was forecasting a spot price of $544 at maturity on July 26, 2007. Similarly on July 1, 2007, the SFI5 was forecasting a November 27, 2007, spot price of $550. To complete this snapshot discussion, the differences between the July 1, 2007, futures prices and the actual corresponding maturity date prices were SFI1 $12, SFI2 $25, SFI3 $16, SFI4 $6, and SFI5 (-$2) reflecting how the forecasted prices can differ from realized prices(Table 3.7).

Table 3.7 Snapshot of SFI 1-5 Futures Prices and Realized Values

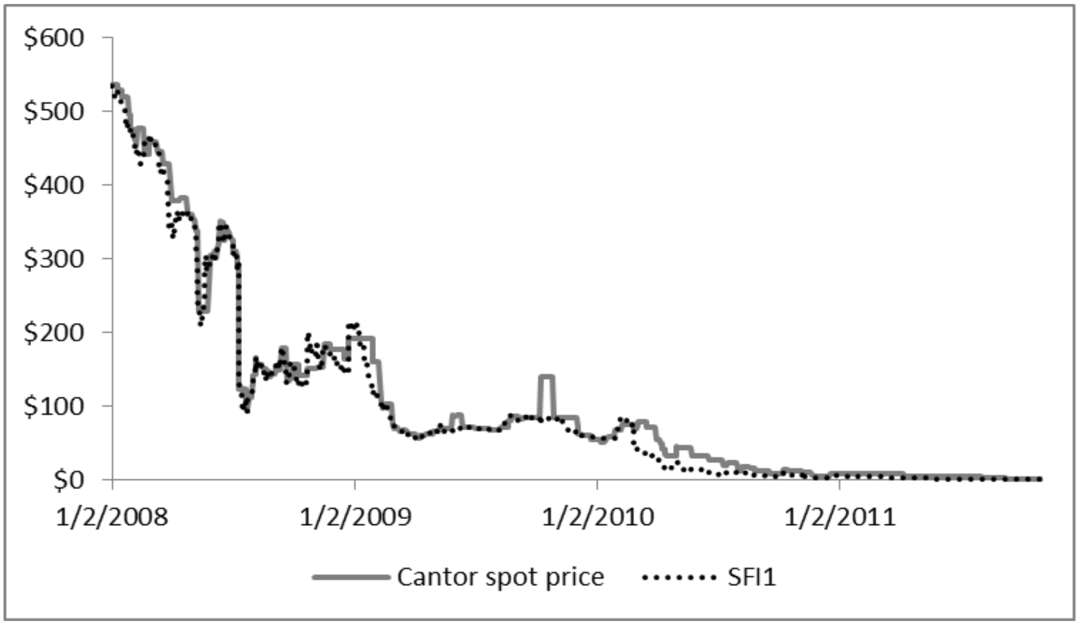
Futures	SFI1	7-Jul	SFI2	7-Aug	SFI3	7-Sep	SFI4	7-Oct	SFI5	7-Nov
7/1/07	$542	SFIN7	$544	SFIQ7	$546	SFIU7	548	SFIV7	$550	SFIX7
7/26/07	$530	M								
8/28/07			$519	M						
9/25/07					$530	M				
10/26/07							542	M		
11/27/07									$552	M
Difference	$12		$25		$16		$6		($2)	

Note: M means maturity. Upon contract maturity, the futures owner receives a transfer of SO_2 permits. SFI(letter)(#) represents the contracts symbol.
Source: Bloomberg (2013, 2014)

[32] This is common practice in futures literature and testing (e.g., Tomek and Gray 1970, Sanders, Garcia, and Manfredo 2009, Schnake, Karali, and Dorfman 2012)

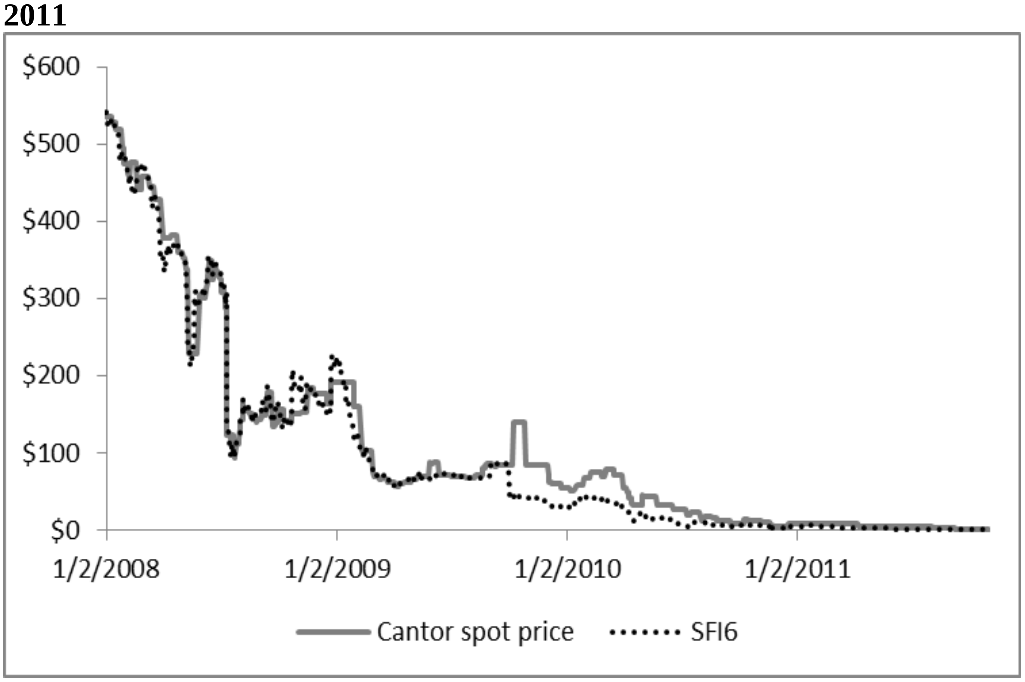
SO_2 Spot and Futures Price and Volume

The SFI front month contract (SFI1) had a trading range of $1-$1615 from December 2004 - 2011 (Figure 3.1). Figure 3.1 displays the weekly SFI1 and Cantor spot prices from 2005 – 2011. The figure illustrates how both prices traded in a very wide price range across years. During this time both prices maintained very similar, but not identical, price movements. The next three figures display prices from 2008 – 2011; Figure 3.2 displays the OTC price and SFI1 futures, Figure 3.3 the OTC price and SFI6 price, and Figure 3.4 the OTC and SFI12 price. In 2008 prices all the prices were trading above $500. Then from 2008 on prices began to decline reaching $2 by 2011. These three figures illustrate how spot and futures maintained similar, but not identical, price movements over this very volatile time period. Further the figures illustrate that as the futures maturity horizon increases the difference between spot and futures prices becomes wider. This potentially reflects the market pricing adjustments for storage and risk across time.



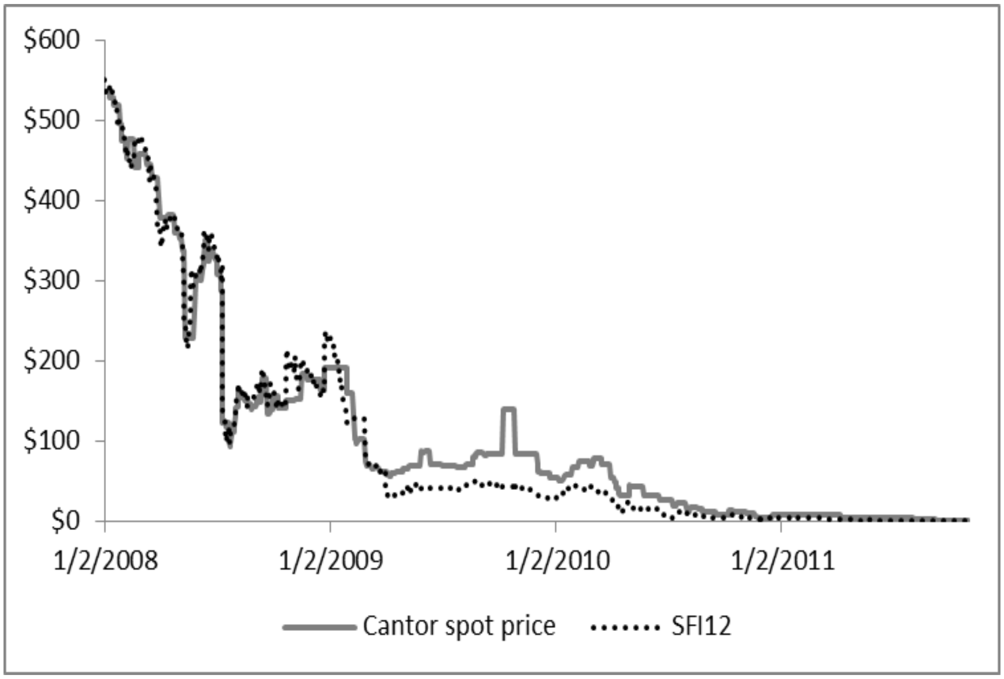
Notes: Prices are in $/permit.

Figure 3.2 SO_2 Cantor OTC and SFI1 Month Ahead Futures Prices from 2008 – 2011



Notes: Prices are in $/permit.

Figure 3.3 SO_2 Cantor OTC and SFI6 Month Ahead Futures Prices from 2008 – 2011



Notes: Prices are in $/permit.

Figure 3.4 SO_2 Cantor Spot and SFI12 Month Ahead Futures Prices from 2008 – 2011

For supply, demand, inventory, and price relationships, Figures 3.1 thru 3.4 can be considered in relation to the stocks-to-use ratio. There is no obvious relationship between the prices and the stocks-to-use ratio from 2003 to 2008. However, from 2008 to 2011, the stocks-to-use ratio increased dramatically while prices fell, which is the expected relationship. This relationship needs to be further investigated.

Table 3.8 provides the SFI 1-12 month horizon mean price, minimum price, and maximum price, and volume, yearly from 2005 to 2011. To illustrate all the monthly horizons the SFI4 - 6, SFI7 – 9, and SFI10 – 12 were grouped together within the table; within the data each series was recorded individually. The SFI 1-12 month yearly average volume was 3m permits from 2006 – 2011, peaking in 2009 with 6.8m permits traded. The futures prices traded in broad range from a high of $1,620 to a low $1; again this volatility is because of policy rule changes and the ultimate market collapse.

Table 3.8 SFI Futures Prices and Volume 2005 - 2011

Year	SFI 1	SFI 2	SFI 3	SFI 4-6	SFI 7-9	SFI 10-12
2005						
Mean price	$906	$785	$750	$883	$884	$1,294
Max price	$1,615	$924	$890	$1,620	$1,625	$1,635
Min Price	$627	$629	$629	$629	$629	$894
Volume	2,875	1,225	na	na	na	na
2006						
Mean price	$704	$600	$623	$687	$688	$729
Max price	$1,585	$821	$824	$1,588	$1,591	$1,597
Min Price	$456	$459	$474	$464	$470	$476
Volume	298,275	22,484,375	21,968,750	87,625	na	na
2007						
Mean price	$526	$528	$527	$531	$540	$578
Max price	$720	$722	$725	$731	$749	$758
Min Price	$390	$392	$393	$395	$398	$496
Volume	2,405,600	597,025	33,225	104,250	13550	59875
2008						
Mean price	$275	$276	$278	$273	$270	$274
Max price	$534	$536	$538	$477	$546	$550
Min Price	$91	$91	$92	$92	$94	$95
Volume	2,665,325	948,225	433,475	786,100	484075	405975
2009						
Mean price	$81	$83	$82	$76	$68	$60
Max price	$215	$216	$218	$225	$226	$230
Min Price	$57	$57	$57	$30	$30	$30
Volume	1,543,200	705,300	939,525	2,547,625	715000	437125
2010						
Mean price	$18	$19	$17	$16	$16	$17
Max price	$87	$73	$45	$45	$45	$45
Min Price	$3	$3	$3	$2	$2	$2
Volume	443,525	171,525	106,425	152,725	379000	548675
2011						
Mean price	$2	$2	$2	$2	$2	$2
Max price	$6	$6	$6	$6	$6	$6
Min Price	$0	$0	$0	$0	$0	$0
Volume	11,750	0	0	6,000	0	1150

Note: All prices are in $/permit; a contract is for 25 permits in total volume calculation.
Source: Own calculations from Bloomberg 2013 data

In 2004, the year of the SFI futures launch, 9.5m permits were issued by EPA, 10.3m were turned in for compliance, and the banked supply was 6.9m permits. During 2004, the Cantor spot price varied between $215 and $722 with a volume of 1.5m permits. SFI futures began trading sparsely in December 2004 with a total volume of only 5,075 permits through December 2005. Then in 2006, SFI trading accelerated substantially with a total volume of 458,275 permits. The SFI volume increase in 2006 illustrates that more permits were traded on the futures than on the Cantor OTC, which had a volume of 390,104 permits for the year. For the year, SFI 1 prices traded in a range of $456 - $1591, similar to that of the Cantor OTC range of $465-$1583.

In 2007, the SFI 1-12 month futures had a volume of 3,213,525 permits compared to the Cantor volume of 994,413 permits. SFI futures had over three times the volume of the Cantor OTC. The increasing volume of futures trading continued in 2008. SFI volume increased to 5,723,175 permits. This was over ten times that of the Cantor volume, 319,482 permits. In 2009, the SFI1-12 futures had twenty-three times the volume as the Cantor OTC; SFI1-12 volume was 6,887,775 compared to Cantor volume of 295,864. By directly comparing the Cantor OTC volume of 3,019,828 permits from 2005 – 2009 against the corresponding SFI1-12 month futures volume of 16,286,850, the difference of 13,267,022 permits results illustrates the substantial impact of SFI futures on permit trading.

In 2009, 2,716 private transactions of past, current and futures vintages representing 15.1m permits were recorded. Of the 2009 trading volume, 4m (26%)

permits were traded between economically unrelated parties[33]. The EPA (2010) estimates the total notional value of SO_2 permits at $1.1b for 2009 (this is computed by using the average Cantor OTC price of $61 for December 2009 based on a volume of 15.1m permits). The 4m of economically unrelated transactions translates to a market value of $244m. Applying the same standards to the 2009 SFI 1-12 month futures, a notional value of $420m was realized on a volume of 6.8m. The futures value was greater than all economically unrelated transaction recorded by EPA for that year. Further in 2009, more SFI permits traded hands (6.8m) than were used as compliances in compliance (5.7m).

3.6 SO_2 Market Events and Factors

SO_2 CAAA Regulation Challenges - Events

The variation in SO_2 emissions and permit prices results from many factors – economic conditions, new and proposed rules, and court challenges of existing rules (Evans and Woodward 2013). The proposed and promulgated rule changes would have essentially altered permit property rights and institutions as designed in the CAAA. Potentially these events would in turn alter the permit market structure. From the perspective of the permit market, the changes created information uncertainty and an increase in price volatility (see Figure 3.1). For purposes of evaluating SO_2 permit spot and futures markets, these events are considered new sources of uncertainty and risks to the market. The events to be discussed come from Burtraw and Szambelan (2009),

[33] Technically, any SFI futures contracts that were delivered against would be included within the EPA number; however, there is no way to separate them out. By ignoring this fact, the point is conveyed more clearly. If one considers futures within that category, then other trades would actually be decreased and the point made strengthened.

Schmalensee and Stavins (2012), Chan et. al. (2012), and Evans and Woodward (2013). Some highlights of the changes provide context for interpreting the price movements.

On December 17, 2003, the EPA proposed the Clean Air Interstate Rule (CAIR). This rule sought to alter how EPA regulated particulate matter (PM) to account for regional effects. CAIR would create new regulations that altered the permit property rights. In attempting to deal with regional pollution, CAIR proposed creating a set of ratios for plant emissions based on the state where a plant was located. Beginning in 2010, CAIR proposed that certain states must turn in permits at a ratio of 50% of current compliance use standards; then in 2015, the ratio would fall to 35% of current compliance use standards. These ratios implied that one permit was not equal to a ton of SO_2 for the selected states. Also, CAIR proposed allowing states to opt out and create their own compliance mechanism. Thus by limiting the ratios to values less than one, CAIR would require a larger number of permits to be used in overall compliance. CAIR represented a challenge to the SO_2 permit market rules and the homogenous permit structures established under the initial CAAA permit policy. On December 17, 2003, the CAIR proposal announcement date, the Cantor price was $215 and within one year permits were trading at $700. Thus, permit prices increased by 325% as the market attempted to evaluate the costs of compliance under the reduced ratio standards. Permit prices continued to increase as the market continued to incorporate the effects of the new rule. Cantor spot prices reached highs of $1626 and $1583 in 2005 and 2006 respectively

Similarly as SFI futures began active trading, their prices reached a high of $1615 in 2005 and $1585 in 2006[34].

The next set of influences arose through court challenges. North Carolina challenged the EPA rule on June 27, 2006, arguing that the state's ability to meet the National Ambient Air Quality Standards (NAAQS) was inhibited by cross-state SO_2 emissions. On the filing date, Cantor and SFI1 prices both closed at $615. Oral arguments were held in March 2008 with North Carolina arguing that CAIR would not protect North Carolina from cross-state emission damages. By the time oral arguments had finished, spot prices had dropped to $380 (SFI1 $349) a decline of $225 or 39% (SFI1 $266 or 44%) from the initial filing in June 2006.

On July 11, 2008, the court ruled for North Carolina and vacated CAIR in its entirety finding that states should be prohibited from damaging other states through cross pollution (North Carolina v. Environmental Protection Agency 2008). The ruling implied that buying permits to assure compliance with emissions limits was an insufficient remedy for CAIR compliance if the emitted SO_2 would materially harm another state's air quality. Further, the court found that EPA had no statutory authority to alter CAAA permit policy language as written and passed into law by Congress (North Carolina v. Environmental Protection Agency 2008). The permit market reacted with a decline in spot permit prices from $287 to $123 on that day (July 11, 2008) representing a 57% decline. Similarly, SFI1 futures prices went from $298 to $123, a 56% decline. Overall

[34] At times, the SFI futures prices will be presented in parentheses following Cantor Spot prices throughout the discussion. Also, the Cantor price will be referred to as just the spot price.

permit prices were very volatile for July 2008, ranging from $325 to $93 (SFI1 $324-$91).

Subsequently, EPA requested a rehearing on September 28, 2008, and the court took arguments considering the prospect for temporarily reinstating CAIR on October 21, 2008. On October 21, 2008, spot prices closed at $142 (SFI1 $141). During this period, Congress also debated new legislation that would have enacted CAIR as a statute and used the CAAA permits as the ratio mechanism (Frass and Richardson 2012, Evans and Woodward 2013).

A court ruling on December 23, 2008, left CAIR and the CAIR Federal Implementation Plans -- including the CAIR trading programs -- in place until EPA issued a new rule to replace CAIR. The permit market reacted with prices rising from $164 to $192 (SFI1 $147-$211), a single day increase of 17% (SFI 44%).

Then on July 6, 2010, the EPA proposed the Transport Rule to control SO_2. The rule represented a response to the court's remand of CAIR. In the three days following the proposal, prices dropped from $26 to $19 (SFI1 $8-$4), a 27% (SFI1 50%) decline. The Transport Rule became known as the Cross-State Air Pollution Rule (CSAPR) and was implemented in July 2011 at which time OTC prices were $5.50 (SFI1 $1.5) with thinning volume. The rule was promulgated in August 2011 and was structured as an elaborate regional trading program. The elaborate structure was a result of trying to account for regional impacts in equating ratios for different states and plant sources.

For my purposes, CSAPR is a completely new regime for dealing with SO_2 emissions and was separate from CAAA permit trading policy. It established a different environmental objective, by considering both regional and cross state pollution. CSAPR represents an overlapping regulation that effectively displaces the CAAA permit property rights. All CAAA SO_2 permit trading ceased, and the market collapsed shortly after CSAPR was promulgated in August 2011. As a result, October 2011 is considered as the end for any meaningful CAAA SO_2 permit trading. The Cantor SO_2 OTC is no longer a listed market and SFI futures were delisted in March of 2012.

Interestingly, due to CSPAR's complex equating of sources, the rule was immediately challenged in court. On August 21, 2012, CSAPR was vacated by the U.S. Court of Appeals for the District of Columbia. Currently, SO_2 regulations are still being debated with no established long term policy. Further, all of the EPA SO_2 proposals attempt to regulate SO_2 emissions through regional permit markets.

Electricity Sector Market Factors and Events

SO_2 emissions result primarily from electricity production. It follows that the electricity market directly influences the SO_2 permit market. In these production activities, each fuel source produces a different SO_2 emission profile. Of the 4,054 billion kilowatt-hours of electricity produced in 2012, coal accounted for 37%, natural gas 30%, nuclear 19%, hydropower 7%, renewables 5% and petroleum 1%. The majority of power plants in the U.S. are located east of the Mississippi River. Coal is produced from three major seams: the Central Appalachian, Illinois Basin, and Powder River Basin (PRB). Each type of coal carries its own price, produces different levels of electricity per ton, and results in different levels of SO_2 emissions per ton. PRB coal, mined in Wyoming and Montana, is the cheapest to produce and is the lowest in sulfur content. By 1999, PRB coal was used in 95% of Phase I regulated power plants west of the Mississippi and 40-45% of the plants east of the Mississippi (Busse and Keohane 2007).

Central Appalachian coal is more expensive to mine and has high sulfur content. With costs and a time lag, coal plants can switch production from high to low sulfur coal or vice versa. A firm's decision to switch coal sources depends upon the price of coal, the amount of electricity production per ton, transportation costs, permit prices, and regulatory considerations.

Within 2011, over 70% of coal was delivered by rail. Coal accounted for 43% of total rail tonnage and 25% of gross rail revenue in 2011. Coal is a low cost source of electricity not only because of its cost per kilowatt hour of electricity output but also because of cost effective shipping[35].

Technological innovation in fuel used per ton of electricity output and in emissions reduction is another factor that affects the operation of permit markets. Flue gas desulfurization (scrubbers) is the major source for retrofitting existing coal plants to lower emissions. Since the inception of CAAA, the number of installed scrubbers has doubled (Chan et. al. 2012). Specifically through examination of patent data before and after CAAA permit system passage, Popp (2003) found evidence that the permit system led to an increase in the patents associated with an improvement in SO_2 removal efficiency.

Of the 263 units regulated in Phase I, 52% pursued fuel switching or blending low-sulfur coal with higher-sulfur coal, accounting for a 59% reduction of SO_2 emissions (Schmalensee and Stavins 2012).

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[35] Railroad deregulation occurred in the 1976 Railroad Revitalization and Regulatory Reform Act and again in the 1980 Staggers Rail Act. The railroad deregulation allowed railroads to set freight rates. The deregulation led to lower freight rates for coal transportation essentially making long distance PRB coal more competitive.

In the U.S., the electricity sector is the largest emitter of CO_2 emissions. In electricity production, both CO_2 and SO_2 are emitted. Depending on regulatory structure and stringency, CO_2 emissions control had the potential to override SO_2 permit effects on firms' compliance behavior. In the 2007 presidential campaign, all three major candidates supported a national CO_2 cap and trade system, which would have led to an exogenous, long-run decline in SO_2 emissions (Chan et. al. 2012). Once the election was over, with the support of President Obama and key legislators, CO_2 emissions control through permit policy was considered. In 2009, the House of Representatives introduced and passed the Waxman-Markey Bill which would have established a permit trading system for CO_2 emissions control. The bill was considered dead by 2010. However, its potential impacts on SO_2 policy affected permit markets and was closely followed by the power sector[36].

Other macro factors affecting emissions include Hurricane Katrina on August 25, 2005. This storm caused a severe disruption to electricity production and transportation across the U.S. In May 2005, rail track failures affecting delivery of low-sulfur coal from the PRB to Midwestern power plants occurred on both the Union Pacific and Burlington Northern Santa Fe Railroads. The failures caused low-sulfur coal prices in the Midwest to peak in December 2005 at a level three times greater than a year earlier. The financial crises and great recession of 2007 - 2012 also led to a slowing in economic output subsequently resulting in lower electricity demand.

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[36] Through the Clean Air Act the Supreme Court has upheld EPA's right to control CO_2 emissions as a criteria air pollutant. In 2014 EPA announced CO_2 regulations covering the electricity sector which directly impact SO_2 emissions (also a criteria air pollutant) from power plants.

3.7 SO_2 Policy: Conclusion

The CAAA SO_2 permit trading policy marked a new approach to regulating external effects caused by SO_2 emissions. After 25 years of command and control regulations, policymakers sought a market based approach with minimal government involvement. Permit property rights were designed to be bankable with one permit equal to one ton of emissions. Phase I permit trading began in 1995 with the issuing of 8.7m permits. At the end of Phase I in 2000, trading activity had expanded allowing firms to realize gains from trading by equating abatement costs across sources. Additionally, a large permit bank consisting of over one year's supply was available for use at the beginning of Phase II.

Phase II began in 2000 with an expanded coverage encompassing virtually all electricity generating units. In its first year, 10m permits were issued and 11.2m permits were used in compliance. The bank reached a low point in 2005 with just over a seven month permit supply at the current emissions rate. At that point, emissions began to decline below permit issuance levels, reaching a level equal to 5.1m permits in 2010. Thus by 2010, firms had reduced yearly emissions by over 50% while total electricity production rose. The result was that the permit bank exceeded a three year supply at emission levels by 2010. Through these years, regulated firms had an almost perfect record of policy compliance. To facilitate trading activity, OTC spot markets were formed.

SFI SO_2 futures were introduced in December 2004 as an alternative pricing mechanism, marking the first environmental permit futures ever launched. Through electronic trading, SFI futures offered an alternative means to hedge permits, allocate compliance costs through time (inventory allocation), and promote price discovery. SFI volume grew rapidly, peaking in 2009 with over 6.8m permits traded in that year. From 2006 through the end of permit trading in 2011, SFI futures volume was greater than that of the primary OTC market. SFI prices were also very volatile, ranging from $1 to $1615 over the period from 2004 to 2011, as the market responded to an ever changing regulatory environment.

The CAAA SO_2 permit policy was subject to considerable uncertainty over the period with rule changes and court cases beginning in 2003. This uncertainty reflected challenges to CAAA permit property rights as initially passed into law and resulted in extreme price volatility and the ultimate market collapse in 2011.

CAAA SO_2 permit policy was the first to have a futures contract. The SFI futures contract formed a liquid market, facilitated price discovery, and offered intertemporal pricing, all at a low cost. The SFI market achieved this through an independent exchange.

CHAPTER 4

EUROPEAN UNION EMISSIONS TRADING SCHEME FOR CO_2

4.1 Introduction

The European Union's Emissions Trading Scheme (EU ETS) for CO_2 permit trading was created in 2003 by EU Directive 2003/87/EC. The policy was established as a means to control aggregate CO_2 emissions' effect on global temperature rise. The policy represented the first, cross country, permit trading system and covered over thirty European countries. To encompass all the diverse countries, a homogenous permit equal to one ton of CO_2 emissions was created. A futures market was formed to facilitate permit trading and compliance for the over two billion permits issued yearly. The objective of this chapter is to describe the factors that influence CO_2 permit and futures market formation and performance.

The chapter begins by describing the legislation establishing the system and rules for permit exchange. After that background, the influence of specific rules on the market over time is discussed. This includes consideration of how the permits were issued, used in compliance, and affected inventory levels. In the next section the spot and futures markets' prices and trading volume are described. The chapter concludes by discussing events that potentially affected the market performance over time.

4.2 European Union Emissions Trading Scheme (EU ETS) for CO_2

EU ETS Policy

The EU ETS's CO_2 permit trading goal is to reduce 2020 CO_2 emissions by 20% from 1990 levels through the use of permit trading as a means to limit global temperature rise to no more than two degrees Celsius above pre-industrial levels. The EU ETS CO_2

system has three phases: EU ETS Phase I 2005-2007, EU ETS Phase II 2008-2012, and EU ETS Phase III 2013-2020. In October 2014, the EU reached an agreement extending CO_2 permit trading from 2020 to 2030 when it is expected that the program will have reduced emissions by 40% from 1990 levels.

This research examines CO_2 Phase II and III over the years 2008 – July 2014 because permits were identical during both of these phases. CO_2 Phase I was not considered because it was a trial phase, and permits were not allowed to be used in the later phases.

Baseline level emissions in 1990 were 5,574 million (m) tons of CO_2 for the 27 member states in the EU ETS[37]. A breakdown of total emissions by country from 1990-2011 is provided in Table 4.1. Germany, France, and the UK accounted for 46% (2,573m tons) of the total in 1990. The three smallest countries of Luxemburg, Cyprus, and Malta had total emissions of 21m tons in 1990, comprising less than 1%.

[37] All emissions are discussed as CO_2 tons; this is consistent with EU reporting (e.g. EC 2014). However, the EU emissions levels technically represent the CO_2 equivalent of total EU greenhouse gases. CO_2 represents over 80% of total greenhouse gases.

Table 4.1 Total EU 27 CO_2 Equivalent Emissions (Regulated and Nonregulated)

Country	1990	2000	2005	2008	2011
Austria	78	80	93	87	83
Belgium	143	146	143	137	120
Denmark	69	68	64	64	56
Finland	70	69	69	70	67
France	556	559	558	531	486
Germany	1,250	1,041	998	975	916
Greece	105	126	135	130	115
Ireland	55	68	69	68	58
Italy	519	551	574	541	489
Luxembourg	13	10	13	12	12
Netherlands	212	213	209	203	194
Portugal	61	84	88	78	70
Spain	283	379	433	399	350
Sweden	73	69	67	63	61
United Kingdom	767	674	658	630	553
EU-15	4,255	4,138	4,173	3,989	3,631
Bulgaria	110	60	64	67	66
Cyprus	6	9	9	10	9
Czech Republic	196	146	145	142	133
Estonia	41	17	18	20	21
Hungary	99	78	79	74	66
Latvia	26	10	11	12	11
Lithuania	49	20	23	25	22
Malta	2	3	3	3	3
Poland	457	385	390	400	399
Romania	244	134	142	140	123
Slovakia	72	49	51	49	45
Slovenia	18	19	20	21	20
EU-27	5,574	5,067	5,126	4,951	4,548

Notes: All numbers are in millions of tons; the total excludes land use, land use change and forestry (LULUCF)
Source EEA 2013

CO_2 emissions result from the combustion of fossil fuels (coal, natural gas, and petroleum) for energy and transportation, along with certain industrial processes and land-use changes[38]. All CO_2 emission point sources contribute equally in forming aggregate stocks of CO_2. Because geographically diverse firms, industries, and countries' CO_2 emissions affect aggregate levels equally, the law considers a ton of CO_2 emitted in Belgium or a ton of CO_2 emitted in Poland as having the same effect on overall emission levels.

The EU ETS regulates specific industry sector CO_2 emissions that represent 40% of total 1990 emissions[39]. The regulated sectors were power and heat generation, commercial and private aviation, industrial plants for timber products, and energy intensive industries which include oil refineries, steel works and production of iron, aluminum, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, acids and bulk organic chemicals [40]. Within these sectors, any industrial installation is covered with a thermal input greater than 20 megawatts (MW) of electricity. The energy sector is the largest regulated sector. In 2009, the energy sector accounted for 65% of allocated permits and 75% of exercised permits and these proportions are representative of all years (Rickels, Görlich and Oberst 2010).

A permit is equivalent to one ton of CO_2 emissions[41]. Each permit is issued in a given year, termed a vintage year. Permits enter the market in two ways -- as free endowments to firms or through auctions. Permits are issued, held, traded, and turned in

[38] An example of a land-use change is the clearing of a forest.
[39] This means 60% of CO_2 emissions are not regulated.
[40] The aviation sector didn't begin partial participation until 2012 and full participation until 2013. Specific EU industry classification codes can be found using NACE which represents the Statistical Classification of Economic Activities in the European Community (https://joinup.ec.europa.eu/catalogue/asset_release/statistical-classification-economic-activities-european-community).
[41] Permits control CO_2 not carbon; the distinction is made because 1 ton of carbon is equal to 3.67 tons of CO_2.

for compliance through electronic registries. The accounts are standardized based on EU and United Nations data exchange standards to track the vintages, inventory, and transfer of permits. In a given year, the binding cap is the total of free endowments issued plus auctioned permits of that vintage year and any accumulated market inventory (bank).

Enforcement and Reporting

The rules for monitoring and implementation of the EU ETS are outlined in Council Decision No 280/2004/EC and 2003/87/EC. Their objective is to ensure the timeliness, completeness, accuracy, consistency, comparability and transparency of reporting by the EU and its members states. The European Environmental Agency (EEA) is responsible for policy operations. Permits are issued on February 28 of each year. For yearly compliance (Jan. 1 – Dec. 31), the EC must receive a verified emissions report from each installation for the prior year by March 31 of the current year. Permits required for compliance in the prior year are due by April 30 of the current year. For noncompliance, a permit must be submitted in the subsequent year in addition to a fee of €40/ton for CO_2 Phase I and €100/ton for CO_2 Phase II and III. The EEA reports the yearly greenhouse gas (GHG) inventories, CO_2 emission levels, and permit activity to the United Nations Framework Convention on Climate Change in accordance with the Kyoto Protocol targets.

Phase II Permit Distribution Rules

A national allocation plan (NAP) is each member state's rule for permit endowment allocation among the regulated firms within each sector. In Phase II up to 10% of permits could be auctioned. Once each state creates its NAP, the plan is submitted to the EC for approval. During Phase II the aggregate sum of each member state's NAP formed the total permit cap. The EC considers this a bottom up approach to establishing permits caps (EC 2012a).

The majority of NAPs were created based on historical and projected emissions but some member states also used benchmarking, which allows the number of permits issued annually to change based on an established benchmark. All three types of NAP estimates are directly related to firm economic output.

Of the participating countries, the EU-15 (comprising Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the United Kingdom) were bound to participation through a common target commitment to the Kyoto Protocol. The EU15 commitment to the Kyoto Protocol required these countries to decrease CO_2 emissions 8% from 1990 baseline levels. The EU15 Kyoto commitment requires achieving the EU ETS 20% goal by 2020. The other participating countries (comprising Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Iceland, Latvia, Liechtenstein, Lithuania, Malta, Norway, Poland, Romania, Slovakia, and Slovenia) were only bound to the EU ETS directive and did not have a common Kyoto Protocol target. This means that the two types of commitments carry different emission reduction goals on a percentage basis. Even though the EU-15 commitment is different, the two standards are nonetheless enforced under a common agreement: the EU ETS.

CO_2 Phase II NAPs were viewed as complicated, not uniform, and in some cases required several rounds of revision before acceptance. Political pressure for free permits to help maintain cross border competiveness was exerted on member states and industry ministers. Effectively the 27 states were pressured individually from within to get a favorable allocation for their industries to compete in the EU ETS. This is illustrated by the fact that 23 initial NAPs had to be revised lower by the EC (i.e., a more stringent cap was needed than the country proposed). These reductions demonstrate the problems created by having individual states create targets for themselves in aggregate policy formation. The final 2008 cap was set at 1,957m permits; this cap was 368m permits lower than the initial proposals,

Phase III Permit Distribution Rules

Phase III permits are identical to those in Phase II. This was intentionally intended to maintain a continuous program. Phase III runs from 2013through 2020 and covers more than 12,000 power plants and manufacturing installations. The new EU ETS agreement extends the policy and banking provisions until 2030. It encompasses the 28 EU member states, Iceland, Norway and Liechtenstein, as well as emissions from airlines flying between European airports. Permit issuance is based on revised rules adopted as part of the EU climate and energy package on April 23, 2009, the Commission Decision 2010/384/EU in July 2010, and the Commission Decision 2010/634/EU in October 2010.

The revised rules eliminated NAPs and established a harmonized system for endowment allocations across all participating countries, termed national implementation measures (NIMS). This change was a shift to a top down approach for setting permit levels. NIMS use a benchmarking rule for distribution. The benchmarks use the principle of “one product - one benchmark.” Because the benchmark methodology is based on one product, it does not differentiate according to technology, plant size, location, or fuel used. Generally, the benchmarks are set by taking the average GHG emissions from the top 10% product producing installations (EC 2014). The benchmark is then used to set the endowment levels of all firms based on their production levels within that sector.

The rules also increased the use of auctions as a means of distributing permits. In 2013 over 40% of the allowances were auctioned. The proportion is set to increase yearly with over half of the allowances expected to be auctioned by 2020 (EC 2014). The system requires that power companies purchase all permits through auctions (i.e., they no longer receive any free endowments). However power companies in Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Lithuania, Poland and Romania received exemptions from this rule and continue to receive a decreasing number of free endowments thru 2019.

International Emission Reduction Credits

CO_2 Phase II and III allow installations to surrender international emission reduction credits generated through the Kyoto Protocol's flexible mechanisms in order to offset a part of their emissions (EC 2012a). The reduction credits can be created in two forms. The first, called the Clean Development Mechanism, refers to Article 12 which allows Annex B parties (industrialized countries) to invest in emission reduction projects in non-Annex B parties (mainly developing countries). These credits are termed Certified Emission Reductions (CER). These credits were established to allow flexibility in compliance and to promote cross border projects. For example, if an EU firm built wind turbine capacity in Nigeria, this project would qualify for CER credits.

The second form of credits is the Joint Implementation mechanism. It was created in Article 6 of the Kyoto Protocol and allows Annex B parties to invest in emission reduction projects in other Annex B countries. These reduction credits are termed Emission Reduction Units (ERU). They allow industrialized country firms to qualify for credits for emission reduction investments within other industrialized countries.

One ERU or CER is set equivalent to one CO_2 permit in Phase II and III compliance. The EU tracks the use of ERUs and CERs in an electronic registry similar to CO_2 permits. Upon project approval and documentation ERU and CER registries are granted to the account holder. The account holder can then use CER and CER permits in CO_2 compliance, bank them, or sell them. Within the EC documentation and research literature CERs and ERUs are generally counted as a permit because of their equivalence in use; for instance, if a CER was used in CO_2 compliance it would be counted as a permit turned in. From a policy perspective, ERUs and CERs are created by companies' investment projects independently. Thus, their supply flow is separated from the annual EU ETS CO_2 permit issuance.

The maximum number of international emission reduction credits allowed for Phase II 2008-2012 compliance use was 1,400m credits. This represents a possible supply increase of 13.4% to that of the CO_2 issued permits. Phase III allows for an additional 300m international emission reduction credits to be used for a total of 1,700m credits over both Phase II and III (2008-2020). These rules allow CERs and ERUs to potentially influence the supply of permits for CO_2 emissions compliance.

4.3 Data

Three primary types of data are discussed in the following sections and later used in empirical testing.

1) *Actual CO_2 permit issuance, compliance, inventory levels, and international credits (CERs and ERUs)*. The data was collected from the EC website, EEA website, and EU reports (e.g., EC 2010, EC 2014).

2) *CO_2 spot market prices.* The Point Carbon CO_2 over the counter (OTC) market price is a composite price compiled by Point Carbon and used by the European Commission. Daily spot prices from July 2008 – December 31, 2012, and monthly spot prices from January 2013 - July 2014 were purchased directly from Point Carbon (2014). Volume data was not available through Point Carbon in connection with the composite price.

3) *CO_2 futures prices*. The European Union Allowance futures contract served as the primary CO_2 futures contract. EUA daily prices, volume, contract symbols, and open interest for all monthly contracts were gathered from July 2008 – July 2014 as sourced from Bloomberg (2013, 2014).

Point Carbon's OTC price is a composite of prices from CO_2 OTC market housed on Bluenext, Climex, the European Energy Exchange, Green Exchange, ICE and Nord Pool from July 2008 – July 2013. The price is taken as the average of the closing prices reported to Point Carbon by the respective exchanges. In July 2013, Point Carbon changed its OTC spot price series to reflect only prices on ICE's OTC because of extremely thin volume on the other OTCs (Point Carbon 2014). This marked a change in the OTC composition reporting with possible effects from thinning volume on some of the exchanges that affected composition price levels prior to the change.

Next these sources are discussed in the context of permit issuance, supply, and use in compliance along with ERU and CER levels. Spot OTCs and futures volume and prices are then discussed. The price series used in empirical estimation are described in Chapter Seven.

4.4 CO_2 Permit Markets

Phase I Market

For purposes of this research, Phase I is considered a separate trial phase. It did serve several important roles though. It was the first CO_2 permit market. It set up the monitoring, data collection, and reporting system. OTC spot markets and futures markets for trading were formed. At the end of Phase I, these trading mediums transitioned to markets for Phase II permit exchange. Thus, spot OTC markets and futures markets were already identified for permit exchange at the start of Phase II.

CO_2 Phase II (2008-2012) & III (2013 – 2020) Issued Permits

CO_2 Phase II (2008-2012) began in 2008 with the allocation of 1,957m permits covering more than 11,500 industrial instillations in 30 countries[42]. As provided in the initial directive, NAPs were created by each country to establish Phase II caps.

During Phase II, the total of permits issued were 1,994m, 2,024m, 2,070m, 2,084m, and 2,228m permits for 2008, 2009, 2010, 2011, and 2012 respectively (EC 2012a). This total consists of both free endowments and those auctioned. Of this total , auctioned permits were 44m, 66m, 86m, and 87m in 2008, 2009, 2010 and 2011 respectively (EC 2012a). In 2008 Germany, Spain, France, the UK, Italy, and Poland were each allocated several hundred permits for a total of 1,299m permits or 66% of the

[42] The aviation sector was brought into the EU ETS in 2012. Aircrafts accounted for 84m permits in 2012.

total. Table 4.2 provides each nation's Phase II and III (2008-2013) allocation and verified permits (permits used in compliance).

The 2013 permit issuance marked the beginning of Phase III which used the new harmonized permit allocation rules. The total permit allocation was set at 2,084m permits, of which 926m were auctioned (EC 2014). Permit auctions are run by exchanges/brokerage houses for the member states. For instance, the UK auctions are run by the ICE exchange and Germany's by European Energy Exchange.

During Phase II and III, permits used in compliance declined. This reduction likely reflects success in meeting the goal of reducing total GHGs[43]. Twenty-three of the 29 countries decreased the number of exercised permits from 2008 to 2012. Of these, nineteen countries decreased emissions by over one million tons. Italy had the largest decrease in exercised permits of over 38m. During these years Sweden had the largest increase in permit use of over 2.4m.

Table 4.2 CO_2 EU ETS Permits Allocated and Verified in Compliance 2008 – 2012

	2008		2009		2010		2011		2012	
Country	All.	Verified	All.	Verified	All.	Verified	All.	Verified	All.	Verified
Austria	30.2	32.0	31.9	27.3	32.7	30.9	32.6	30.6	35.4	29.6
Belgium	55.4	55.5	56.8	46.2	56.0	50.1	56.6	46.2	61.6	45.1
Bulgaria	38.3	38.3	40.6	32.0	35.3	33.5	41.5	40.0	43.1	35.4
Croatia	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cyprus	4.8	5.6	4.8	0.1	5.4	5.1	5.8	4.6	6.7	4.6
Czech Rep	85.6	80.4	85.9	73.8	86.1	75.6	86.4	74.2	87.2	70.2
Denmark	24.0	26.5	23.9	25.5	23.9	25.3	23.9	21.5	25.2	19.5
Estonia	11.7	13.5	11.9	10.3	11.9	14.5	15.9	14.8	14.3	13.6
Finland	36.5	36.2	37.1	34.3	37.9	41.3	38.0	35.1	40.3	30.7
France	129.6	124.1	128.7	111.1	138.5	115.2	139.5	105.7	160.0	112.9
Germany	388.8	472.7	392.3	428.2	400.5	454.9	400.8	450.3	467.3	468.2

[43] The total of verified permits used in compliance reflects the total emissions emitted in a year; because CERs and ERUs can be used to create permits, they do not alter the verified number of emissions emitted in a year. They do alter the total permit supply.

Table 4.2 (Cont'd) CO_2 EU ETS Permits Allocated and Verified in Compliance 2008 – 2012

	2008		2009		2010		2011		2012	
Country	All.	Verified	All.	Verified	All.	Verified	All.	Verified	All.	Verified
Hungary	25.0	27.2	23.9	22.4	25.7	23.0	25.0	22.5	26.2	22.4
Ireland	20.0	20.4	20.0	17.2	21.0	17.4	21.6	15.8	28.8	26.2
Iceland	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.4	0.4
Italy	211.8	220.7	204.0	184.8	200.0	191.5	195.3	190.0	197.6	182.6
Latvia	2.9	2.7	3.5	2.5	4.5	3.2	4.6	2.9	5.3	3.0
Liechtenstein	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lithuania	7.5	6.1	7.6	5.8	8.2	6.4	8.0	5.6	8.4	5.8
Luxemburg	2.5	2.1	2.5	2.2	2.5	2.3	2.5	2.1	4.8	3.6
Malta	2.1	2.0	2.1	1.9	2.2	1.9	2.2	1.9	2.4	2.3
Netherlands	76.8	83.5	83.8	81.1	84.8	84.7	88.8	80.0	99.4	80.6
Norway	7.5	19.3	8.0	19.2	8.0	19.3	8.4	19.2	9.5	20.5
Poland	201.0	204.1	201.0	191.0	205.6	199.7	207.2	203.0	213.5	197.3
Portugal	30.5	29.9	30.5	28.3	32.5	24.2	33.0	25.0	35.1	26.8
Romania	71.6	64.1	73.7	48.6	75.0	47.3	74.8	51.2	75.6	48.4
Slovak Rep	32.2	25.3	32.5	21.6	32.4	21.7	32.6	22.2	33.5	21.0
Slovenia	8.2	8.9	8.2	8.1	8.2	8.1	8.2	8.0	8.3	7.7
Spain	154.0	163.5	151.0	136.9	151.0	121.5	151.4	132.7	163.6	140.1
Sweden	20.8	20.1	21.1	17.5	23.6	22.7	22.7	19.9	25.9	22.5
UK	214.3	265.1	217.0	231.9	220.6	237.4	223.4	220.9	283.5	247.2
TOTAL(1)	1,957.1	2,119.6	1,967.4	1,873.2	1,998.6	1,938.6	2,016.9	1,904.6	2,228.7	1,950.4

Notes: All numbers are in millions of permits. Slight discrepancies in the data may exist as separate reports were used to describe all the years. Allocated permits only reflect CO_2 permits. A country's allocated permits are then distributed as both free endowments and through auctions. Verified is used to describe the total of permit and permit equivalents (ERUs and CERs) used in compliance for CO_2 emissions emitted in that year. Source: own calculations from EC 2009a, EC 2010a, EC 2012d,

International Emission Reduction Credits

CERs and ERUs provide a supply flow not based on member state emission levels. Through 2013, 1,246m international emission reduction credits were turned into permit equivalents; these could be used for CO_2 compliance, held as inventory, or sold. Table 4.3 provides a breakdown of these credits from 2008-2013. Over these years 164m, 159m, 248m, 429m, 713m, and 264m credits have been used respectively. Of total international emission reduction credits, CERs accounted for 59% (731m) and ERUs 41% (515m). Of the CERs total, China, India, South Korea and Brazil accounted for over 90% through 2011 (EC 2012b). The main suppliers of ERUs have been Ukraine, Russia, Eastern and parts of Central Europe (e.g., Bulgaria) (Nazifi 2013). At the end of Phase II, international emission reduction credits accounted for over 10% of EU ETS permit compliance (EC 2012b).

Table 4.3 Permit Inventory, CERs, and ERUs 2008 – 2013

Year	2008	2009	2010	2011	2012	2013
CERs	82	78	114	177	214	66
ERUs	0	3	20	75	285	132
Total Bank (CO_2, CER, and ERU permits)	-80	94	288	652	1,430	2,100

Notes: Inventory is [(Year total -exercised)+prior year inventory]. Because this table was created from different data reports and includes CERs and ERUs registered in a year, it is not directly comparable to table 4.2.
Source complication of numbers drawn from annual reports EC 2009a, EC 2010, EC 2011, EC 2012b, EC 2013a, EC 2014

Permit Inventory and Compliance

The permit inventory is composed of permit market inventory and permit equivalents (CERs and ERUs) that have been turned into permits. The inventory of permits from 2008 to 2013 was -80m, 94m, 288m, 652m 1,430m, 2,100m respectively. Because Phase II started a new market, the initial permit inventory was zero. Over each consecutive year, the inventory levels grew.

A stocks-to-use ratio can be used to further understand permit supply, demand, and inventory conditions (see equation 3.1). In December, the lowest yearly inventory point, the stocks-to use ratio was just under one month in 2009, over one and a half months in 2010, over four months in 2011, over eight months in 2012, and over a full year's supply by 2013. It is reasonable to assume that the excess permit supply will continue to grow because Phase III runs through 2030, a large inventory currently exists, CERs & ERUs can be created adding to supply, and current yearly permit issuance is greater than yearly compliance.

EU ETS compliance was over 99% in 2013 (EC 2014). By the compliance deadline, less than 1% of the participating installations had not surrendered allowances for their 2013 emissions. These installations are typically small firms and together account for less than 1% of emissions covered by the EU ETS (EC 2014). These compliance numbers are representative of compliance for all years over the 2008 through 2013 period (EC 2014).

Spot OTC and Futures Market Prices

The Phase II and III CO_2 permit market consisted of a spot market, futures market and a link to the international emission reduction credit market through the equivalence compliance rule. The spot pricing mechanisms were private negotiations, OTC markets, auctions and brokerage facilitated transactions. OTC markets were housed on Bluenext, Climex, the European Energy Exchange, Green Exchange, ICE and Nord Pool. These six markets generate Point Carbon's spot CO_2 OTC permit price. OTC permit prices traded from €15.53 – 28.66 in 2008, €9.95 – 15.06 in 2009, €12.57 – 16.35 in 2010, €7.93 – 16.96 in 2011, €5.95 – 8.65 in 2012, and €2.87 – 6.37 in 2013.

The ICE EUA futures contract is the primary futures market instrument. An EUA Phase II and III futures contract was for a lot of 1000 emission permits. EUA contracts are physically deliverable by the transfer of emission allowances from an acceptable trading account of the selling member to the specified trading account of ICE Clear Europe (ICE 2013). EUA contracts could also be delivered from the trading account of

ICE Clear Europe to an acceptable trading account of the buying member (ICE 2013). EUA contracts mature the last Monday of the contract month. If the last Monday is a non-business day or there is a non-business day in the four days following the last Monday, the last day of trading will be the penultimate Monday of the delivery month. EUA futures transaction fees were €2.00 per side per contract for members' proprietary business and €2.50 per side per contract for nonproprietary business. This translates into an EUA transaction fee 0.017% of a permit's value based on 2010 prices. Appendix C provides a EUA futures contract specification sheet and also lists all of the futures contracts that traded from 2008 – 2013.

Table 4.4 EUA Futures and OTC Price and Volume from 2008-2013

Year	EUA 1	EUA 2	EUA 3	OTC
2008				
Mean price	€ 22.67	€ 23.00	€ 23.34	€ 21.32
Min Price	€ 13.72	€ 14.36	€ 14.36	€ 14.50
Max price	€ 29.33	€ 30.53	€ 30.53	€ 29.38
Volume	1,083,622,000	191,715,000	92,057,000	N/A
2009				
Mean price	€ 13.21	€ 13.35	€ 13.48	€ 13.16
Min Price	€ 8.06	€ 8.06	€ 8.06	€ 8.25
Max price	€ 15.63	€ 15.87	€ 15.87	€ 15.15
Volume	510,603,000	616,621,000	787,323,000	N/A
2010				
Mean price	€ 14.38	€ 14.48	€ 14.37	€ 14.32
Min Price	€ 12.22	€ 12.41	€ 12.41	€ 12.24
Max price	€ 16.42	€ 16.47	€ 16.52	€ 15.64
Volume	549,345,000	653,573,000	1,112,260,000	N/A
2011				
Mean price	€ 12.52	€ 11.61	€ 12.76	€ 13.02
Min Price	€ 6.45	€ 6.48	€ 6.56	€ 6.41
Max price	€ 16.79	€ 16.73	€ 16.96	€ 16.81
Volume	805,328,000	282,330,000	299,517,000	N/A

Table 4.4 (Cont'd) EUA Futures and OTC Price and Volume from 2008-2013

Year	EUA 1	EUA 2	EUA 3	OTC
2012				
Mean price	€ 7.39	€ 7.40	€ 7.39	€ 7.35
Min Price	€ 5.72	€ 5.74	€ 5.76	€ 5.89
Max price	€ 9.28	€ 9.30	€ 9.12	€ 8.97
Volume	1,146,982,000	390,862,000	383,414,000	N/A
2013				
Mean price	€ 4.50	€ 4.50	€ 4.51	€ 4.50
Min Price	€ 2.87	€ 2.87	€ 2.88	€ 2.75
Max price	€ 6.37	€ 6.38	€ 6.40	€ 6.53
Volume	N/A	N/A	N/A	N/A

Note: All prices are in €/ton; each EUA contract is for 1,000 permits (1000 tons). Due to futures listing, only the 1-3 month series were created. 2013 individual volume series were not gathered.
Source own calculations from Bloomberg (2013, 2014) and Point Carbon (2014)

ICE EUA futures were listed for trading at the start of Phase II. In 2011, EUA futures contract listings were changed. There are now monthly maturing contracts which begin trading three months in advance. Quarterly futures contracts are listed three years in advance for the months of March, June, September, and December. Because of the contract listing changes, the data series used are EUA1 -3 month horizons (see the futures section in Chapter Three for a description of futures series formation). Table 4.4 provides a detailed description of the yearly EUA1-3 month futures and OTC mean, minimum, and maximum price along with total volume. ICE EUA1 month ahead futures traded in the range €13.72-29.33 in 2008, €8.06-15.63 in 2009, €12.22 - 16.42 in 2010, €6.45 - 16.42 in 2011 and €5.72 - 9.28 in 2012, and €2.93 – 6.53 in 2013. Slight variation between the prices exists but overall values largely maintain similar ranges.

Total EUA volume of permit traded in 2008, 2009, 2010, 2011, 2012 and 2013 we 1,991m, 3,775m and 4,266 m, 5,442m, 6,464m, and 7,257m respectively. Futures volume has increased in every year of the market. After 2009, more permit futures traded than were used in yearly compliance.

Figure 4.1 graphs the EUA1 month futures and spot OTC prices from July 2008 – July 2012. This figure and Table 4.4 illustrate how prices began above €25 in 2008. Since then prices have declined to a trading range of €5 - 10 by 2014. The table also illustrates how prices traded in a wider yearly range in the beginning years. The figure and table imply that as prices declined, yearly volatility (yearly price range) also appears to decline. Intuitively, the price and volatility decline could be a result of the supply and demand conditions as reflected in the stocks-to-use ratio. In agreeing to extend the EU ETS through 2030, the question of how to deal with the excess supply is a hotly debated topic which has to still be agreed upon.

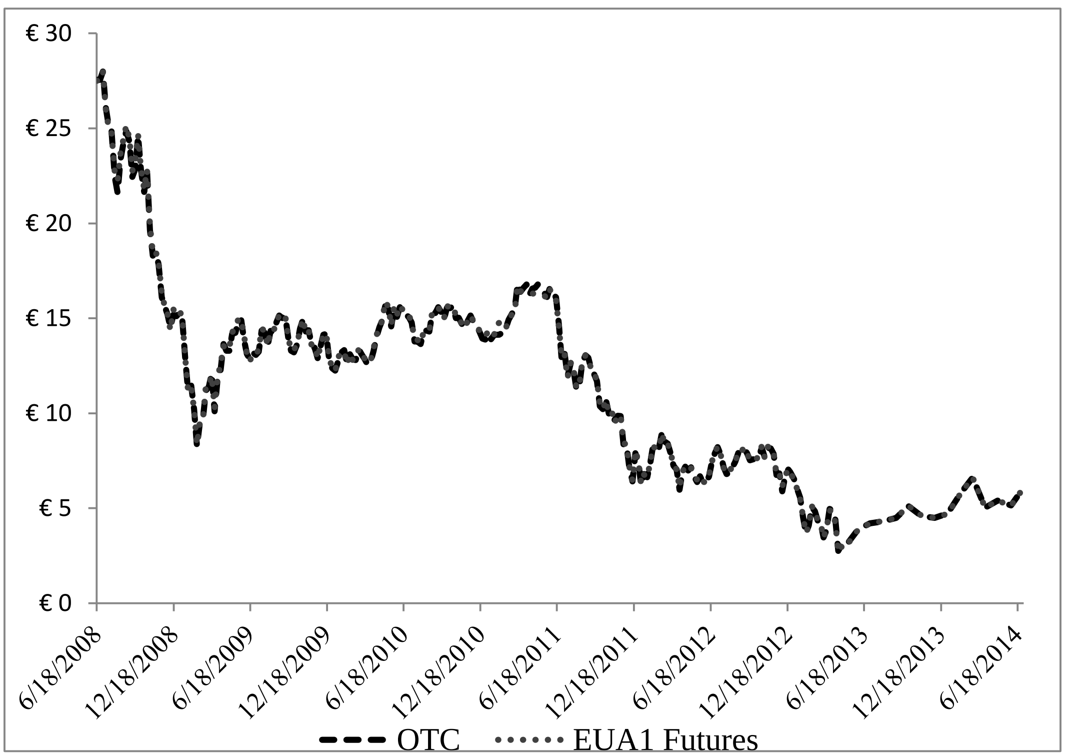

Figure 4.1 CO_2 OTC and EUA1 Futures prices 2008 – 2014

CO_2 Market Events

The global financial crisis that began in 2008 has and is still impacting the EU economies. The crisis has resulted in some member states' economies falling into recession. From 2008 – 2012 EU the annual real GDP growth rates were 0.4%, -4.5%, 2.10%, 1.6% and -0.4%(Eurostat 2013). Because CO_2 emissions are linked to economic output, part of the reduction in emissions can be attributed to weak economic conditions[44].

In 2009 exploitation of value added taxes (VAT), termed carousal fraud, was revealed. The exploration arose through different tax treatments of CO_2 permits, CERs, and ERUs occurring between countries. Because each EU country maintains its own tax system, some countries enacted tax credits for CO_2 permits, CERs, and ERUs whereas other countries implemented taxes on CERs and ERUs; the rationale was that because CERs and ERUs arose through investments in other countries they should be taxed. These different tax systems' rules between countries could be profitably manipulated through transferring credits between countries for compliance use. This cross country multi-jurisdictional framework allowed trading exploitation of an estimated €5000m (EC 2012a). In 2010 changes to the EU ETS were adopted to counter VAT fraud (Europol 2009).

The second event uncovered in 2010 involved registry hacking of over 28m permits. This led to the closure of all EU ETS registries in January 2010 for several days

[44] For instance in 2008 the financial crises was estimated to reduce energy related CO_2 emissions by 3% (IEA 2009). This factor has been recognized by EC reports which acknowledge that while CO_2 prices are a contributing factor, the EU economic crises is also a major cause of the overall reduction (EC 2012c).

as new safeguards were put in place. This hacking episode only affected government registries and OTCs; because ICE maintained its own accounts and security, EUA futures continued trading. Both episodes had the potential to impact price efficiency reflected by the large number of permits involved.

4.5 CO_2 Policy: Conclusion

The EU ETS CO_2 permit trading policy marked a new cross country approach to regulating CO_2 emissions externalities. The system implemented a long term (2005 – 2030) market based approach for reaching desired goals. Permit property rights designed one homogenous permit which could be stored for compliance use during any year over 2008 – 2030 (Phase II, III, and IV).

At the beginning of Phase II in 2008, a transparent electronic registry system existed for the issuance, exchange, monitoring, and enforcement of policy performance. Phase II started a new market through the issuance of 1,994m permits across 30 countries. The permit total gradually increased, reaching 2,228m by 2012. In the first year of trading, no permit inventory existed. During Phase II, 96.9% of permits were given as free endowments and the rest were auctioned. Phase III started in 2013 and maintained a permit property right structure identical to that of Phase II. This allowed the permit inventory to be carried over for use in Phase III. However, in Phase III 40% of permits were now auctioned.

In Phases II and III, additional permit supply was created through the use of up to 1,700m international emission reduction credits, generated through the Kyoto Protocol's flexible mechanisms, . By 2013, 1,246m international emission reduction credits had been exercised, thus adding to market supply. Between the international emission credits and more permits being issued than used in compliance, an inventory of permits began to accumulate. After only five years of trading, this resulted in over a full year's supply of permits (2,100m) existing in 2013.

The EUA futures contract successfully began trading in 2008. In addition several spot OTCs also formed for permit exchange. Futures and OTC prices traded in a wide range of €13 – 30 during the first year. Since then prices have steadily declined, reaching a range of €2 – 6 by 2013. An active futures market has existed during all of these years with volume rising substantially over time. Futures volume started at over 1,990m permits in 2008 and had reached over 7,200m by 2013. Interestingly, this volume increase occurred while prices declined each year and additionally traded in narrower yearly range (i.e., a less volatile range). Understanding futures performance in the CO_2 permit market is important because the EU ETS will be actively trading through 2030.

CHAPTER 5

FUTURES CONTRACTS, MARKETS, AND PRICES

5.1 Introduction

This chapter provides context for understanding how futures markets work and how they can be used for permit pricing and emissions compliance. To further understand what futures trading means for these markets, the remainder of the chapter first defines futures' contracts and their primary roles. Next it describes how futures markets function. The theory of storage is then used to explain permit futures prices based on permit, futures, and other commodity characteristics. An extensive literature on agricultural, energy, and metal commodity futures exists along with a rich literature on the empirical performance of EU CO_2 EUA futures.

5.2 Futures Contracts and Markets

Futures Contracts and Contract Series

Due to commodity market volatility (uncertainty), producers and consumers seek ways to mitigate risk (Pindyck 2001, Tomek 1997, Tomek and Robinson 2003). Alternative pricing mechanisms to address price risks for commodities include forward contracts, OTCs, options, futures, and swaps. Of these, futures contracts are the most widely used[45]. Their trading characteristics have been shown to serve firms' desire to manage price uncertainty associated with storable agricultural, energy, and metal commodities (Carlton 1984, Pindyck 2001, Tomek 1997, Tomek and Robinson 2003, Garcia and Leuthold 2004).

[45] Exchange traded futures volume in 2010 was over 22 billon contracts worldwide with a notional value of $601 trillion for commodities and financial assets (Chance and Brooks 2013).

Futures contract for storable commodities have been described as having three primary roles (Pindyck 2001, Tomek and Gray 1970, Tomek 1997). The first is to provide a pricing mechanism that allows firms to manage the risk associated with uncertain commodity prices over time through the process of hedging (Pindyck 2001, Tomek 1997, Tomek and Robinson 2003)[46]. The second is to facilitate assimilation of decentralized agents' information in prices, termed "price discovery" (Tomek and Robinson 2003). Third, futures play an important role in the temporal allocation of inventories (Tomek and Gray 1970, Working 1948, 1949).

A futures contract is a legal agreement to either take delivery (buy) or provide delivery of (sell) a specified quantity of an underlying commodity with a particular grade (quality) at a defined future maturity date and agreed-upon price (CME 2014, Tomek and Robinson 2003). The maturity date is the date at which the futures contract is settled by delivery of the physical commodity. At delivery, ownership changes from a futures contract to a supply transfer of the commodity under specific terms and procedures governed by the rules of the exchange (CME 2014). A futures contract is a standardized contract whose specifications are fixed; the only participant-determined variable is the price.

An example will illustrate how a futures contract works. In July a buyer of a December futures contract at a price *x*, agrees to take delivery of underlying commodity in December for *x*. Similarly, the seller agrees to make delivery of the underlying commodity in December at this price.

[46] A futures hedge uses a futures contract as a temporary substitute for a later spot transaction; it is taken to offset market risk.

Futures contracts are created in a contract series, defined as a set of contracts representing the same underlying commodity but at a series of different maturity horizons. Each contract in a series has the same grade specifications. Within a series only two variables differ among contracts, the maturity date and the contract price. The exchange sets the different contract maturity dates in a predetermined fashion, and participants interact to determine the prices. Table 5.1 gives a sample European Union Allowance (EUA) CO_2 futures contract series quote sheet. The sheet shows the prices on February 11, 2015, for EUA futures contracts maturing in February 2015 (€7.16), March 2015 (€7.18), December 2015 (€7.26), December 2016 (€7.39), December 2017 (€7.51), and December 2020 (€7.92). For instance, on February 11, 2015, participants could have purchased an EUA CO_2 December 2017 futures contract for €7.51, which upon maturity would become a supply transfer of EU CO_2 permits at that price. The table illustrates how a futures contract series can provide pricing information at differing time horizons and facilitate trading on this date for later delivery of the underlying commodity.

Table 5.1 European Union Allowance CO2 Future (EUA)

Maturity date	Feb-15	Mar-15	Dec-15	Dec-16	Dec-17	Dec-20
Price	€7.16	€7.18	€7.26	€7.39	€7.51	€7.92

Prices were taken Feb 11, 2015, from the ICE exchange. These contracts represent a sample of the total contract series trading on this date.

Contract series can have monthly, quarterly, or yearly contracts listed several years out. Currently some commodity futures trade eight years out, such as the European Union Allowance (EUA) CO_2 futures and the West Texas Intermediate crude futures.

Once a futures market is functioning, it is common for the same contracts to simply be continuously offered in different years on a rolling basis as one contract matures[47].

Exchanges and Futures Market Rules

An exchange is an independent for-profit entity that creates the futures contracts, houses the futures market, maintains all of the contract trading activity, insures counterparty risk, disseminates information, posts prices, and enforces performance[48]. The exchange generates profits by charging a small fee on the trades it facilitates[49]. Because the exchange's profits come from transaction fees, its incentives are to promote a large competitive market. Therefore, the exchange's incentives are separated from that of futures contract buyers and sellers.

The futures market itself is a double auction where buyers and sellers simultaneously submit bids and offers for futures contracts. Information flow is promoted through price transparency, defined by the Chicago Mercantile Exchange (2014) as:

> "Market prices that are universally available in real time, where all market participants have equal access to the same markets and prices at the same time. This facilitates a fair and anonymous trading environment where the best bid and best offer have priority. Creating a level playing field."

[47] For example in December 2014, the December 2014 EUA futures contract would mature and be delisted. Simultaneously, a new EUA futures contract with a maturity in December 2022 would be listed and begin trading.

[48] Counterparty risk refers to risk that the opposite party to a contract will not fulfill their terms of the agreement.

[49] For example ICE, the company that listed both the SFI and EUA futures contract, is a publicly traded company listed on the New York Stock Exchange. In 2006, the EUA CO_2 futures (SO_2 SFI futures) contract transaction fee was 0.0145% (0.0114%) of a permit's total value.

These prices are quoted electronically. Trading can also be conducted electronically or through open outcry[50]. Both trading mediums promote open access for firms' and speculators' trading participation alike. All that is required for participation is a valid trading account (i.e., meeting minimum credit and balance standards). Contract performance is insured by the exchange, a unique feature that eliminates any counterparty risk and reduces information costs.

Once the futures contract and market rules are determined, performance depends on the level of trading behavior. Measurements of market activity are volume and open interest. Volume is the number of contracts traded within a defined period such as a day, month, or year. In a contract series, the volume of contracts traded typically declines as the time horizon until maturity lengthens (Tomek and Robinson 2003). Over the life of a single futures contract, volume typically increases as the time to maturity approaches (Tomek and Robinson 2003).

Open interest refers to the total number of long (ownership rights) or short (sale rights) positions outstanding without an offsetting position taken by the contract holder (CME 2014). For an established futures contract, volume and open interest commonly exhibit consistent patterns over a contract lifecycle (Tomek and Robinson 2003).

[50] Open outcry is a method of public auction for making bids and offers in the trading pits of futures exchanges.

Aspects of a successful futures contract have been discussed by Gray (1978), Silber (1981), Carlton (1984), Black (1986), Hieronymus (1996), Leuthold, Junkus and Cordier (1989) and Tashjian (1995), and Tomek and Robinson (2003). These attributes include:

- Homogeneity of the underlying commodity.
- Accurate representation of the underlying commodity at delivery.
- Storable inventory.
- Large volumes of supply and demand must be large and reflect many independent users.
- Market volatility.
- Demand for the underlying commodity.
- Hedging demand from industry.
- Attractive to speculators.
- Neutral contract terms between buyers and sellers.
- Low transaction fees and information costs.

Finally, the overall futures marketplace must be competitive (Tomek and Robinson 2003)[51].

Futures vs. Forward Contracts

This section will discuss forward contracts and compare them with futures contracts. A forward contract is an alternative pricing mechanism for permits to be delivered at a later date. Forward contracts are privately negotiated between parties and so contract quantity, delivery point, and grade specifications are unique to the contracting parties. Forward contracts also contain counterparty risk because they are individual agreements; this is unlike futures contracts where the exchange ensures performance.

[51] Despite the motivation for optimal contract design and widespread futures use, forty percent of new contracts listed in the United States are delisted and cease trading within five years (Carlton, 1984). This pattern has not improved over the years and is especially true for industries new to futures contracts (Thompson, Garcia and Wildman, 1996; Bollman, Thompson and Garcia, 1996).

Payment timing and delivery can follow identical terms for forward and futures contracts if the dates match. For instance if both contracts are entered into in time *t* with payment and delivery to occur at a later time *T*, then both have identical terms. However, there is a cash flow difference between forward and futures contracts.

Futures contracts require a small margin -- a percent of total futures value (similar to a performance bond) -- to be put into an account at time (t) when the contract is negotiated. The margin is held by the exchange. The futures are then marked to market daily, with additional margin balances required if prices move unfavorably to the initial position and margin balances returned after favorable price moves. Upon contract completion, either through delivery or exiting of the position, the exchange returns the margin balance. The literature has examined this aspect in detail, with a consensus that margin requirements can be ignored for practical purposes when modeling price performance (see Hull 2011, Pindyck 1994, French 1983, Tomek and Robinson 2003)[52].

In summary, there is one main difference between futures and forward contracts. The difference is that futures are standardized contracts whose terms are set in a predetermined fashion. Through this design, futures markets are more transparent and easily accessible to participants. Due to unique specifications of each individual forward contract, they typically have higher search and information costs, exhibit counterparty risk, and have higher transaction fees. The result is that futures markets typically have a much higher volume of trading activity than forward contracts (Pindyck 2004, Tomek

[52] For a proof of the theoretical differences between forward and futures performance caused by interest rates and margins, see Cox, Ingersoll, and Ross (1981).

and Robinson 2003). Thus for homogenous goods, forward markets do not provide the same competitive low cost market as futures.

5.3 Theory of Storage

Literature

The theory of storage has been used to characterize the spot and futures prices for storable commodities such as energy, metal, and agricultural products whose primary use is as an intermediate output or input in an industry production process (Working 1949, Fama and French 1987, 1988, Pindyck 1993, 2001, Hull 2011, and Tomek 1997)[53]. Because of storability, firms benefit by carrying inventories in order to avoid production process disruptions (Working 1949, Fama and French 1987, 1988, Pindyck 1993, 2001, and Tomek 1997). These storage benefits are sometimes referred to as a "convenience yield". For example if a supply disruption (stockout) threatens crude supply, an oil refinery derives a convenience yield benefit from maintaining crude oil inventories to ensure that it can avoid disruption in the production and delivery of refined gasoline. In this case, firms may wish to hold some amount of crude inventory even if market conditions suggest that there is no economic incentive to actually store the commodity (Pindyck 2001).

In this setting, it is convenient to describe price expectation for a storable commodity as composed of the spot price adjusted for the risk free return minus the net benefits of storage. Within the commodity market literature, research has described the

[53] Commodities are generally classified into two categories. The first is consumption commodities that are used in firm production of goods whose price follows the theory of storage (Hull 2011). The second is investment commodities such as gold, which are held for an income return and thereby related to the broad market (Hull 2011).

net benefits of storage as the "net convenience yield" (e.g. Fama and French 1987, 1988, Pindyck 1993, 2001, and Tomek 1997). Total storage cost consists of physical storage cost plus the cost of having capital tied up in inventory. The total storage cost is often referred to as the "cost of carry" (Working 1949, Pindyck 2001)[54].

The price of a futures contract represents the market's expectation of what the spot price will be at the delivery date. Using the theory of storage terminology, the price for a futures contract should equal the spot price adjusted for the risk-free rate of return over the time remaining until maturity of the contract minus the net storage benefits from having inventory on hand to meet potential disruptions[55].

Permit Futures Price Formation

Within the U.S. SO_2 and EU CO_2 permit trading systems, emissions can be considered as outputs produced (emitted) from an industrial process in the coproduction of one or more marketed goods. To comply with regulatory policy, a permit must be submitted annually for each ton of the emitted pollutant. Both types of permits are considered "storable" because of banking provisions. Firms may hold an inventory of permits for later use. Thus it would seem, the theory of storage provides a convenient means to describe permit and permit futures prices.

A permit price expectation described in the theory of storage can be stated as

(5.1) $$E(q_T) = (1 + r_{t,T})s_t - \vartheta_{t,T}$$

[54] For this research, the terms total storage costs and net storage benefits will primarily be used for clarity. It is recognized that within the commodity literature "cost of carry" and "net convenience yield" are the standard terms.

[55] Working's view was that futures prices were determined by storage benefits based on expected market conditions.

where q is the permit price, $r_{t,T}$ is the risk-free interest rate at t spanning the time from t to T, s the spot (OTC) permit price, and ϑ the net storage benefits (convenience yield) (Working 1949, Tomek 1997, Pindyck 2001) [56]. The net storage benefits for holding an inventory of permits from t to T are the banking benefits received (inventory value) minus the total inventory storage costs. A permit's total cost of storage is only the spot price times the risk free return, reflecting capital costs. There are no physical costs of storage for permits because of the electronic registry use. Thereby, the net convenience yield of storage can be considered as the net value of storage costs and benefits. The value is subtracted because storage benefits from t to T are accrued.

Permit futures contracts are for later delivery of a predefined number of permits. As a result, their price represents the market's expectation of what the permit price will be at the delivery date[57]. It follows that a permit futures price is

$$F_t^T = E(q_T) \tag{5.2}$$

where q is the permit price at T, F is the futures price for a later contract maturity date T - denoted with a superscript.

Net convenience yield values at a point in time through equation (5.1) and (5.2) may be expressed as

$$\vartheta_{t,T} = (1 + r_{t,T})s_t - F_t^T . \tag{5.3}$$

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[56] The risk free rate at a point in time t, is the annual risk free rate (Tbill for US SO_2 and LIBOR for EU CO_2) at t, multiplied by the ratio of days the period covers from t to T expressed as

$$r_{t,T} = (T - t)/365 * r_t .$$

[57] This discussion is meant as a general setup and leaves basis considerations for Chapter Six.

This convention illustrates how at time *t*, the spread between futures and spot prices reflects the markets valuation of storage benefits[58].

A zero net convenience yield occurs if the value of the storage benefit is equal to the cost of storing permits; it means that firms receive no excess storage benefits from having a permit inventory on hand. This implies that the risk of permit supply disruptions on overall firm profits/production is minimal. A zero value can occur due to several factors such as a large permit supply in relation to expected demand or low permit price volatility.

A net convenience yield greater than zero indicates that the firm receives excess benefits (a premium) by holding permit stocks to avoid potential production disruptions, termed *backwardation*. Commodity market conditions that might create such benefits are low levels of inventories, price volatility, or uncertain later events (e.g. supply disruption or policy change). For instance, a permit stockout can cause a firm to shut down production of good *y* because it cannot meet permit compliance requirements in the coproduction of emissions. Backwardation results in the holding of stocks when intertemporal spreads are negative (i.e., spot price + storage cost > futures price) (Tomek and Gray 1970, Pindyck 2001) [59]. Weak backwardation indicates spot price > futures price but less than the storage cost.

[58] It is through equation (5.3) and its extensions that the literature has examined storage benefits, spot prices, and futures prices (e.g. Kaldor 1939, Working 1948, 1949, Brennan 1958, Telser 1958, Pindyck 1993, 2003, Fama and French 1987, 1988, Tomek and Gray 1970, Tomek 1997, Bailey 1998, Yoon and Brorsen 2002, and Williams 2001).

[59] If a firm did not need permits until the later contract maturity date and the market was in backwardation, the holding of a permit inventory would result in the firm paying for excess storage benefits they did not need; to avoid paying for these benefits they could buy the futures whose later date maturity price does not include the prior storage benefits.

A market in *contango*, on the other hand, reflects a negative net convenience yield value. It is represented by the spot price + cost of storage < futures price. Overall in each scenario the storage relationship over time is reflected through spot and futures contract spread. Thus, an important role of a futures market is to value storage benefits and costs. Through this role, futures allocate inventory in relation to expected later conditions which serves to stabilize markets through time (Tomek and Gray 1970).

5.4 Conclusion

Futures contracts are designed as standardized contracts for later delivery of an underlying commodity. They are listed in a contract series which provides a temporal constellation of future prices on any given day. The futures contract and its corresponding market are created and housed by an independent exchange. Exchanges create profits through charging small transaction fees on the futures trading activity. In so doing their incentive is to create a competitive market with transparent prices and open access for agent participation. Through these traits, futures attract decentralized trading among heterogeneous agents. In turn, the trading activity serves to assimilate all of the independent pricing information over the contract series. Thus, futures facilitate permit price discovery by creating a wealth of intertemporal market based pricing information.

Permit futures represent the market's forecast of later permit prices which can be described through the theory of storage. This futures price should equal the spot price adjusted for the risk-free rate of return over the time remaining until maturity of the contract minus the net storage benefits from having inventory on hand to meet potential supply/production disruptions. When considering production decisions, these futures prices can then help guide inventory allocations and emission decisions over time. If policymakers hope to achieve a competitive and robust permit market system, futures contracts offer the potential to vastly expand the constellation of permit pricing, trading activity, price discovery, and smooth temporal allocation.

Of the three key roles futures can provide (risk management, inventory allocation, and price discovery), risk management through hedging was not directly addressed. Chapter Six will discuss how futures can be used to mitigate permit price uncertainty.

CHAPTER 6

PERMIT SYTEMS SUBJECT TO PRICE UNCERTAINTY

IN THE PRESENCE OF A FUTURES MARKET

6.1 Introduction

This chapter outlines the role that markets in futures contracts for tradable permits can play in improving the performance of permit systems for environmental externalities. An extensive literature on tradable permits exists. However to my knowledge, permit futures' influence on marginal production decisions as an instrument for responding to permit price uncertainty has not been considered. This chapter provides a description of how futures can be used to manage the price uncertainty associated with permits in emission compliance decisions. The expected utility framework developed in Chapter 2 is extended to allow a firm that produces both a marketable good (e.g., electricity) and the associated emissions regulated through a tradable permit system access to a permit futures market. Firms can use the current futures price to determine the efficient level of emissions. The futures price reflects the marginal cost of compliance from using permits to meeting regulatory emissions standards. Since there is no uncertainty about that price, production is not affected by a firm's risk aversion or its expectations regarding the permit price. By hedging with futures, firms can mitigate the permit price uncertainty. Under the assumption that all firms optimally hedge, the theoretical model shows that futures' hedging allows firms to maintain production of the marketed good at the policy cost minimizing level, thereby separating the output decision from the emissions control decision.

The next section of this chapter provides motivation for why futures should be considered in permit systems. Next comes an outline of a model of the firm in the presence of a futures market. The results with a futures market are then compared to those without a futures market under otherwise identical assumptions. The final section summarizes the results and discusses their implications for policy design.

6.2 Futures Literature and Permit Context

There is a rich literature on the ability of futures markets to reduce risk for the underlying "commodities" these contracts represent. Beginning with Kaldor (1940) and Working (1948, 1949), this research has considered the theoretical and empirical relationship between spot and futures prices. A futures hedge takes a temporary position in a futures contract as a substitute for a later spot market transaction; it is taken to help manage/reduce market risk associated with a commodity that may be needed later. Because futures can be bought or sold across time, these contracts can be used to insulate against unfavorable price movements. Within this context, product price uncertainty has been examined by Anderson and Danthine (1981, 1983a, 1983b), Feder, Just, and Schmitz (1980), Holthausen (1979), Newberry and Stiglitz (1981), Rolfo (1980), Stein (1984), Paroush and Wolf (1986, 1989), Kawai and Zilcha (1986)[60]. Their findings demonstrate that futures can help reduce the effects of risk, inform decision making, and be used to hedge later output price risk. Further if a futures contract is a perfect substitute for the underlying commodity, current decisions can be based on the current futures price. This allows output to be independent of the spot price risk, creating what is termed

[60] Input uncertainty has also been considered in a similar fashion (e.g., Schmidt and Statman, 1980, Paroush and Wolf 1992, Anderson and Danthine 1983a).

the “separation property” (Feder, Just, and Schmitz 1980). This eliminates any negative effects that the uncertain spot price would have on supply levels.

For futures to be a perfect substitute for the underlying commodity, there must be a zero basis value between spot and futures prices. Basis is defined as the difference between spot and futures prices that is caused by timing, quality, and location differences in exchange (Tomek and Robinson 2003). The basis is unique to each specific market. For instance, the location (the basis risk) of an oil refinery in need of crude for producing gasoline is unrelated to the factors affecting crude price levels (overall supply and demand). If the refinery’s location is different than where crude futures delivery occurs, this would result in a basis effect. Agricultural, energy, and metal commodity markets typically exhibit non-zero basis values.

If positive basis values are present, the separation property does not hold (Stein 1979, 1984, Anderson and Danthine 1981, 1983a, Paroush and Wolf 1989). Basis values limit the ability of futures to reduce the spot market’s price risk (Anderson and Danthine 1981). This is because futures are no longer able to offset all the risk of the uncertain underlying commodity’s price. As a result, if a futures hedge is taken in the presence of basis risk, some degree of later spot market price risk persists. Exceptions to this result can occur if there are multiple ways to hedge risk, either through the use of both futures and forward contracts or through multiple futures contracts (Anderson and Danthine 1981, Paroush and Wolf 1989).

The literature has also considered two other factors that can affect futures’ ability to reduce risk. The first is production uncertainty, characterized as uncertainty regarding the final quantity of a good to be produced. For example when a farmer plants an annual corn crop, uncertain weather over the growing season can cause the final quantity produced to be considered uncertain. Production uncertainty has been shown to degrade futures performance in managing risk (Newberry and Stiglitz 1981, Anderson and Danthine 1983a and 1983b, and Chavas 2004). Generally speaking, if the quantity produced is uncertain, then the corresponding futures position used as a hedge may not equal the realized quantity produced.

Permit Context

The SO_2 and CO_2 policy rules and markets have important features that influence how the implementation of futures markets and their modeling properties are expressed. The most important of these are that:

- Permits can be banked across years and maintained in electronic registries.
- The permit spot and futures prices have varied within a wide range and exhibited large percentage movements over time.
- Both the SO_2 and CO_2 futures were actively traded as reflected by trading volume.
- Both sources of emissions can be considered as outputs produced (emitted) from an industrial process in the coproduction of one or more marketed goods.
- The marketed goods responsible for creating these emissions through their production process are subject to uncertainty[61].

These properties can be considered within the context of storable commodities. This is because of permits represent emissions emitted as part of a production process, rules for banking, the presence of an active futures market, and a wide spot market price

[61] For example Schennach (2000), considers both permit and electricity demand uncertainty as key aspects in evaluation of banking effects.

range paralleling other storable commodities traits. Within this framework, an expected utility model is used to describe how permit futures can reduce product (permit) market price risk, drawing on Feder, Just and Schmitz (1980), Anderson and Danthine (1981), and Chavas (2004). The exposition assumes the futures market to be ideal, in the sense that the current futures price represents the best information at that specific time as to what subsequent permit prices will be[62]. First, the firm setup is discussed. Then the question of how a permit futures hedge works is described. Next I evaluate how permit futures perform in reducing permit price uncertainty effects.

Theoretical Models

The firm, market conditions, and production decisions considered in this chapter are identical to that described in Chapter 2. It follows that in production of a marketed good *y*, emissions *z* are generated which require an identical number of permits to be turned in for policy compliance. In addition, the firm receives a free endowment of permits, labeled ζ . Table 6.2 provides a detailed description of the variables and their properties.

Production decisions are made in the first period *t* with output realized in a second period *T* (i.e., a static two period model). The production technology is represented by two production functions, $y = f(x)$ and $z = g(y)$. At the time of the firm's production decision, uncertainty exists regarding the marketable good's final price *p* as well as the permit price *q* ($p = \mu + \sigma e$ and $q = \eta + \lambda \varepsilon$ see table 6.2). It follows that all output production decisions are made in the presence of two uncertain output prices. This

[62] Assuming an ideal futures market is consistent with the literature (Feder et. al. 1980, Anderson and Danthine 1981, and Chavas 2004)

translates into an uncertain revenue of py and uncertain permit compliance cost of $q(g(y)-\zeta)$.

To this point the firm and market setup is identical to that in Chapter Two, where the firm's objective function was characterized as

(2.1) $$EU(w+py-q(z-\zeta)-C(vx))=EU(w+\pi),$$

where E is the expectations operator based on the subjective probability distributions of the random variables p and q. For further detail see Chapter Two and Table 6.2.

Introduction of a Futures Market

Assume now that the firm has access to a futures market in tradable permits that can be used to hedge later permit needs, potentially mitigating some or all of the permit market price risk. The futures market is assumed to be ideal in the sense that it generates futures prices that are the best representation of subsequent permit prices, based on current information. Permit futures actively trade during the decision period t, with a unit price of F for a contract that matures in the output period T. In the decision period, the futures price F is considered a known market price. Therefore, the firm can use that price in the decision making period t to hedge later period T permit compliance needs. The number of permit futures hedged is H. Viewed from the decision period t, the price for the futures contract at maturity in the second period T is considered unknown, represented by ψ.

A general hedging example within this setup illustrates the trading mechanics. A hedge uses a futures contract as a temporary substitute for a later spot transaction in the second period T. In this example, the hedge is used to offset permit product market price risk, which is it the permit price uncertainty or the product market price uncertainty in period *T*. The firm plans to produce a quantity *y* of the marketed good which will require *z* permits for compliance at *T*. Suppose the firm purchases *z* permit futures as a hedge (*H* = *z*) in the decision period *t* with a permit unit price of *F*. To exit the hedge in the output period *T*, the firm simultaneously sells the futures position *H* at a permit unit price of ψ and buys *z* permits at the spot permit unit price of *q*. See Table 6.1 for an outline of the hedging process.

Table 6.1 A Regulated Firm Permit Compliance Needs Hedging Example

Time Period	Futures quantity (*H*)	Permit quantity (*z*)	Purpose	Price
Decision period (t)	Buy *H* futures at *F*	N/A	Hedge risk	Known
Output period (T)	Sell H futures at ψ	Buy *z* permits at *q*	Own physical permits for compliance	Unknown
Total costs	$-FH + \psi H$	$-qz$		

Notes: *F* is the futures price in *t* (i.e., it is known at *t*), ψ is the futures price in *T* (it is unknown at *t*), *q* is the spot permit price at *T* (it is unknown at *t*).

The compliance cost of using the hedge is given by

(6.1) $$-F_t H + \psi_T H - q_T z \, ,$$

Each term represents a separate trade; 1 futures trade valued at $F_t H$ in period *t*, 1 futures trade valued at $\psi_T H$ in period *T*, and 1 spot trade worth $q_T z$ in period *T* for a total of 3 trades. In this example, if the permit futures unit price at maturity is equal to the spot permit unit price $(\psi_T = q_T)$, then the final price paid using the hedge is F_t per permit. This illustrates how the hedge would allow the firm to price all of its permit compliance needs using the known decision *t* period futures price, thereby removing the effect associated with the unknown later period-T spot price. However to understand the final permit price paid and the overall role of futures, we must further define what comprises permit spot and futures prices in the maturity time period *T*. We must also consider the production process that gives rise to emissions and the need for permits.

The permit futures price at maturity (second period) is ψ, which is assumed to be a random variable characterized by $\psi = \eta + \lambda\varepsilon + \varsigma\theta$, with a mean $E(\psi) = \eta$ where ε is a random variable with mean zero, and λ is a mean-preserving spread parameter for the distribution of *q* (noting these values are the same as that of the spot permit). Additionally the *basis*, defined as the difference between spot and futures prices, is represented by θ, a random variable with a mean zero and ς is a mean-preserving spread parameter for the distribution of ς. Within an asset pricing context, ε represents intrinsic price risk. The θ basis risk is the difference between spot and futures prices that is caused by timing, quality, and location traits unique to a specific market. Thus, the two risks can be treated as statistically independent, such that $E(\theta\varepsilon) = 0$. It follows that the variance of the futures price is $\text{var}(\psi) = \lambda^2 \text{var}(\varepsilon) + \varsigma^2 \text{var}(\theta)$. See Table 6.2 for a list of the variables described.

By comparing the conditional futures maturity price $\psi = \eta + \lambda\varepsilon + \varsigma\theta$ with the conditional permit price $q = \eta + \lambda\varepsilon$, we see that the first two terms are the same and the difference is $\varsigma\theta$ (the basis effect). This value reflects any differences due to timing, quality, and location factors between permit spot and futures. The output period date is set equal to the futures contract maturity/delivery date, so that no basis effects are caused by timing differences between spot and futures in the output period. Because an electronic registry is used to facilitate spot and futures exchange, no physical permit transportation costs for user location differences apply; therefore, there is zero basis effect due to location. Further, because regulatory policy defines only one homogenous use in compliance for a SO_2 (CO_2) permit which was identically matched to SFI (EUA) futures delivery terms, it follows that through transfer of permit registries at delivery, no permit quality (grade) specification differences exist between spot and futures; hence, there is zero basis effect due to quality differences. Combined permit spot and futures traits in exchange result in a zero basis value in the output period (at the futures maturity date)[63]. Even though the basis is zero, it is initially included because a zero basis is a unique and favorable trading property of storable electronic permits that is worth highlighting. A zero basis improves a firm's ability to hedge risk and in turn aids in creating a successful permit futures market. Intuitively, this is because the spot and futures prices are for the same homogenous permit whose trading and compliance use is solely electronic. As a result, the two prices are based on identical information.

Maximizing Expected Utility with Futures

In the presence of a futures market the firm's uncertain revenue is

$$py - q(g(y) - \zeta) + (\psi - F)H .$$

The firm's initial wealth is represented by *w*. Its terminal wealth at *T* is:

$$w + py - q(z - \zeta) + (\psi - F)H - v' x ,$$

[63] Outside of the static model, if the basis between spot and futures was not zero at maturity, arbitrage potential would exist. However with respect to the maturity point in time, no negative consequences would occur because if one owned futures as a hedge and spot>futures (unfavorable basis), one could simply take futures delivery electronically at no cost to avoid any basis differences. Conversely if spot < futures, the futures buyer (long) has profitable arbitrage potential through selling the futures and buying spot permits for a realized gain equal to the basis.

which is uncertain[64]. Table 6.2 provides a list of the variables described in this setup. The decision maker is assumed to maximize expected utility of wealth and to have risk preferences represented by the utility function $U(\cdot)$.

The firm's objective function then is

(6.2) $EU(w + py - q(g(y) - \zeta) + (\psi - F)H - C(v, y)) = EU(w + \pi)$,

where *E* is the expectations operator based on the subjective probability distributions of the random variables *p, q,* and *ψ*.

Table 6.2 List of Variables Defined

Variable	Description
w	wealth
y	good output, with a production function of *y=f(x),* where *f'>0* and *f''<0*
p	the good's output price in period T, which (from the perspective of the production decision in period t) is assumed to be a random variable with a mean $E(p) = \mu$ in which $p = \mu + \sigma e$, where *e* is a variable random with mean zero and *σ* is a mean-preserving spread parameter for the distribution of *p*
q	the expected period T permit (emissions output) output price, which is assumed to be a random variable with a mean $E(q) = \eta$, and is characterized by $q = \eta + \lambda\varepsilon$ where ε is a random variable with mean zero, and *λ* is a mean-preserving spread parameter for the distribution of *q*
ψ	the period T futures maturity output price, which is assumed to be a random variable with a mean $\mathrm{E}(\psi) = \eta$, characterized by $\psi = \eta + \lambda\varepsilon + \varsigma\theta$, where *λ* ε carry the same measures as the spot permit. Additionally, the *basis* is represented by θ, a random variable with a mean zero and mean-preserving spread parameter ς for the distribution of ψ .
z	emissions output (number of permits required), with a production function of *z=g(y),* where *g'>0* and *g''<0.*
ζ	free permit endowment
F	the period *t* futures price (decision making period)
v	a vector of input prices
x	input quantity, with a cost function of $\sum_{i=1}^{n} v_i x_i = c(v, y)$
E	expectation operator for the subjective probability distribution of the random variables
$U(\cdot)$	utility function, which satisfies $U' \equiv \partial U / \partial w > 0$ and $U'' \equiv \partial^2 U / \partial w^2 < 0$

[64] Time discounting is not considered for clarity; otherwise terminal wealth would reflect $w(1+r)$.

The firm's production decision is described by

(6.3) $$Max_{H,x,y,z}\{EU(w+py-q(z-\zeta)+(\psi-F)H-\sum_{i=1}^{n}v_i x_i:\ y=f(x)\ \ z=g(y)\}.$$

See Table 6.1 for a description of the variables. Upon simplification, the production decision may be written as

(6.4) $$Max_{H,y}\{EU(w+py-q(g(y)-\zeta)+(\psi-F)H-C(v,y))\},$$

see (D.1). This allows the firm's decisions to be characterized entirely in terms of the good *y* output and the permit futures quantity *H* taken as a hedge[65]. The firm's profit is

$\pi=w+py-q(g(y)-\zeta)+(\psi-F)H-C(v,y)$.

The first order necessary conditions for optimal output *y* and *H* are

(6.5) $$\frac{\partial EU}{\partial y}:\ E[U'\cdot(p-qg'-C')]=0$$

and

(6.6) $$\frac{\partial EU}{\partial H}:\ E[U'\cdot(\psi-F)]=0.$$

For convenience the first order conditions can be rewritten by setting $A_i=(p-qg'-C')$ and $A_j=(\psi-F)$, such that $E(U'A_i)=E(U'A_j)=0$. Next drawing on Feder, Just, and Schmitz (1981) and by using Feder (1977, Lemma 4), it may be shown that

(6.7) $$A_i=-g'*(A_j)$$

(See Appendix D.2). The Hessian, denoted as ∇^2, formed from (6.5) and (6.6) and using (6.7) is

[65] Noting eq. (6.4) implies uncertainty does not affect the cost function; future research could examine cost uncertainty implications.

$$\nabla^2 = \begin{bmatrix} E(U''A_i^2) - g''E(U'q) - c''E(U') & -E(U''A_i^2)/g' \\ -E(U''A_i^2)/g' & E(U''A_i^2)/(g')^2 \end{bmatrix}$$

(derived in Appendix D.4). The second order condition is

(6.8) $D = \left|\nabla^2\right| = -g''E(U'q) \cdot E[(U''\cdot A_i^2)/(g')^2] - c''E(U') \cdot [E(U''\cdot A_i^2)/(g')^2] < 0$

from (D.4). Because $\nabla^2 H<0$, (7) describes a saddle point reflecting a local maximum, it follows that the saddle point found would be in the positive production range. Additionally, because of permits' negative revenue effect, $y = 0$ is an alternative production possibility. That would be the case if, because of permit regulations, a firm is no longer profitable and shuts down.

Using eq. (6.7) to modify eq. (6.6) gives (6.b) $E[U'\cdot(g'F - g'\psi)] = 0$. Equating equations (6.6b) and (6.5), using the conditional expectations of p, q, and ψ output prices and conditional covariance for q and ψ (see D.5), the optimal choice of y satisfies the following condition

(6.9) $\frac{\partial EU}{\partial y}: \quad \mu = C' + Fg' - \frac{Cov(U', p)}{E[U']}$

where μ is the expected good's price, the firm's marginal cost of production is $C' \equiv \partial C / \partial y$ and the marginal cost of emissions compliance with respect to y is $Fg' \equiv F\partial g / \partial y$. The good's uncertain price effect is $\frac{-Cov(U', p)}{E(U')}$ which reflects the good's expected price relationship with utility.

The futures price F reflects permit demand associated with production of good y which, in turn, reflects the incremental cost of compliance in that period. Therefore in this static framework, Fg' is the firm's marginal compliance cost from producing one more unit of y.

It follows that uncertain spot permit price expectation *E(q)* no longer negatively affects the firm because futures can be purchased in the decision period for a known price as a perfect substitute for permits[66]. Thus, the separation property holds and the production decision for good *y* is independent of the permit price risk. If the basis was not equal to zero, then futures would only be a partial hedge of risk and permit price uncertainty would again affect firm behavior.

Certainty Equivalent

The certainty equivalent can describe the intuition of how futures alter uncertainty effects through the risk premium. Specifically, the risk premium describes terms associated with the futures position in relation to the variance of profits. These terms can illustrate how permit price risk is mitigated. The discussion in Chapter 2 defines the risk premium as a measure of the private costs of risk borne by a firm.

In the presence of a futures market, *R* is the certain amount a firm is willing to pay to become indifferent between receiving the risky return

$$(w + py - q(g(y) - \zeta) + (\psi - F)H - C(v, y))$$

versus the sure amount

$$[E(w + py - q(g(y) - \zeta) + (\psi - F)H - C(v, y)) - R].$$

Using a Taylor approximation derived in appendix (D.6), the variance of profits in this setting is

[66] A distinction is made in that permit prices no longer affect the firm negatively; in that it is possible to use the covariance of permit futures with the good's price to further reduce risk, a beneficial role termed a cross hedge. The cross hedging effects would be reflected in $\frac{-Cov(U', p)}{E(U')}$. A cross hedging discussion is included below.

$$\begin{aligned}\text{var}(\pi) = {} & y^2 \text{ var}(p) - g(y)^2 \text{ var}(q) + \zeta^2 \text{ var}(q) + H^2 \text{ var}(\psi) \\ & -2yg(y) \text{ cov}(p,q) + 2y\zeta \text{ cov}(p,q) + 2yH \text{ cov}(p,\psi) \\ & -2g(y)\zeta \text{ var}(q) - 2g(y)H \text{ cov}(q,\psi) + 2\zeta H \text{ cov}(q,\psi)\end{aligned} \tag{6.10}$$

which includes effects for the good's product price variability, permit price variability, and futures maturity price variability. The futures position taken in period *t* is *FH*. Because its value was known when the hedge was entered, the current futures price *F* does not influence profit variability. The variance of profits in eq. (6.10) illustrates how the futures position ψH at time *T* has a sign opposite to the permit price term. The appendix (D.6) then goes on to derive the risk premium as $R \approx \frac{r}{2} \cdot [\text{var}(\pi)]$, where the variance of profits is reflected by eq. (6.10).

It follows that the certainty equivalent with futures is

$$Max_{y,H}\{\mu y - \eta(g(y) - \zeta) + (\psi - F)H - C(v,y) - R\}. \tag{6.11}$$

The first-order necessary condition with respect to good *y* is

$$\partial CE / \partial y : \mu = C' + Fg' + R' \tag{6.12}$$

with the marginal risk premium equal to

$$R' = (r)[y \text{ var}(p) + H \text{ cov}(p,q) - g(y) \text{ cov}(p,q) + \zeta \text{ cov}(p,q)]. \tag{6.13}$$

The marginal risk premium consists of five terms. The first two terms represent (1) the firm's risk preference and (2) the good's price variance times the quantity produced. The next terms representing (3) the futures position *H*, (4) the quantity of emissions produced, and (5) the endowment quantity, all with respect to the covariance of *q* and *p*. The marginal risk premium found in eq. (6.13) highlights that the variance of permit prices, *q* no longer influences risk aversion.

The third, fourth, and fifth terms are all concerned with the good's price uncertainty, with the net of the terms representing any beneficial role futures can play in cross hedging the good's price risk. A permit futures cross hedge is defined as any risk reduction in the price of the good that can be achieved through use of a permit futures contract; this position would be in addition to the pure hedge position taken to offset permit price risk. A cross hedge discussion is included because a firm's production processes create both the good and the emissions. This implies that through the same production processes the two outputs could potentially have positively or negatively correlated market factors and costs which may give rise to use of a cross hedge[67]. In this case the production relationship implies a positive relationship. Following Anderson and Danthine (1981), the permit futures cross hedging potential for the total quantity of good *y* is represented by

$$(6.14)\quad cross\ hedge = -y[\frac{\text{cov}(p,\psi)}{\text{var}(\psi)}].$$

The sign of (6.14) corresponds to the position taken; a positive (negative) sign corresponds to a long (short) futures position. The cross hedge ratio reflects how many futures should be used per the marginal unit of good *y* to reduce the good's price risk. It can be expressed as

$$(6.15)\quad \rho_{p,\psi} = \left[\frac{E(\sigma e \lambda \varepsilon)}{E[(\lambda\varepsilon)^2]}\right] / \left[\sqrt{\frac{E[(\sigma e)^2]}{E[(\lambda\varepsilon)^2]}}\right]$$

[67] For instance, the concept of cross hedging with futures or options has been considered for crude and refined gasoline. Alternatively, for permits a cross hedge could use natural gas, coal, or electricity futures to reduce permit price risk.

where $\rho_{p,\psi}$ is the correlation coefficient between the *T* period futures price ψ and good's price *p* (this is solved in (D.7) following Anderson and Danthine 1981). The correlation coefficient has a value $0 \leq \rho_{p,\psi} \leq 1$, where a $\rho_{p,\psi}$ =*1* would means that permit futures' prices and the good's prices are perfectly correlated (i.e., futures are a perfect substitute for the good). A correlation less than one in absolute value would mean that futures can eliminate some of the good's price risk effects. Because of the cross hedging relationship just described, the third, fourth and fifth terms will only be present if futures provide cross hedging benefits.

By assuming that no cross hedging benefits exist, it can be shown that permit prices no longer enter the marginal risk premium in eq. (6.13). For instance if the good's price and permit futures price are uncorrelated $\rho_{p,\psi}$ = *0*, then the third, fourth, and fifth terms of (6.14) become zero; this leaves only the good's price variance, $y\,\text{var}(p)$. Thus, the risk premium in (6.14) is only based on the good's price uncertainty and contains no additive risk from permit price uncertainty. This outcome happens because the zero basis allows futures to be a perfect substitute for permits[68]. In turn, the futures can be purchased in the decision period at a known price *F*. Permit futures prevent the uncertainty in permit prices from further adding to the effects of risk aversion.

Connecting Expected Utility and the Certainty Equivalent with Firm Supply

By comparing the certainty equivalent with expected utility it may be shown that

(6.16) $$R' = -\frac{Cov(U', p)}{E(U')},$$

[68] The absence of a permit price variance term in (6.14) is also a result of this effect.

where the firm's marginal risk premium from producing one more unit of output *y* may alternatively be expressed as this covariance term. This link illustrates that the risk premium can be used to characterize price uncertainty in both production contexts (Chavas 2004).

In the presence of a futures market, the first-order conditions in equation (6.9) $\mu - Fg' - C' + Cov(U', p)/E[U'] = 0$ can be expressed through the risk premium as

(6.17) $\mu = Fg' + C' + R'$

where *R'* is the marginal risk premium, *C'* the marginal cost of production, and *Fg'* the marginal compliance cost for emissions emitted in generating a unit of good *y*. This equation shows that the marginal output of *y* is based on equating the good's expected price μ to the marginal compliance cost, *Fg',* of producing one more unit of good *y*, the marginal cost, *C',* of good *y* production, and the marginal risk premium *R'.* It demonstrates that the three cost components are additive in arriving at the firm's total cost. The firm's risk preferences do not interact with the uncertain permit price to negatively affect production because the marginal compliance cost is based on the known futures price *F*. Thus, the supply of good *y* with respect to permit policy costs is based on incremental compliance costs only. Further, *ceteris paribus*, permit price risk will not alter good *y* production and policy cost minimization is achieved.

6.3 Conclusion

The results presented in this chapter demonstrate that with a permit futures market production decisions can be based on the current futures price. In this role, futures provide a known price for equating the incremental compliance costs of emission control.

As a result, price uncertainty can be mitigated, thereby allowing supply of the marketed good at the cost minimizing level.

The current framework considers production quantities as certain once decisions are made in the first time period. Production uncertainty at the time decisions are made compared to realized output in the later period is a relevant consideration. Future research should extend this model to consider production uncertainty in one or both of the marketed good and emissions.

A relevant policy consideration is that the specification of the theoretical model assumes a one to one linkage between output and emissions. Abatement activity can change this relationship. This linkage is not considered here. Future research should examine this topic. Abatement activities could involve building new plants or retrofitting existing plants with better emission control technologies. The model could be altered to include abatement factors that lower the level of emissions as represented by $z = g(y)$ per unit y of output. If such a model framework was solved for abatement activity, the futures price would serve as the price signal to harmonize abatement activities among firms.

Because policymakers must select regulatory action in the absence of complete cost information, these results demonstrate that a futures market can provide important social benefits in allocating resources, achieving pollution reductions, and mitigating permit price uncertainty. Thus, from a policy cost perspective, futures contracts can enhance a permit systems' performance.

CHAPTER 7

EMPIRICAL METHODS AND RESULTS

7.1 Introduction

The analysis in the previous chapters describing the role of futures contracts is based on the assumption that an ideal futures market exists. This chapter empirically examines the SO_2 and CO_2 futures markets to determine if support, over the specific time frames examined, is shown for the presence of an ideal futures market. These results will suggest whether those market prices can be relied upon to support emission decisions and hedging of permit price risk as the theory suggests.

This chapter has six main sections. The first links the empirical tests with the futures assumptions maintained in the theoretical context. The second section tests if the futures market leads the spot market in reflecting new permit pricing information. The third section presents some initial insights into the efficiency of these futures markets by focusing on futures performance in forecasting permit prices and their ability to encompass all of the information contained in an alternative forecast. The fourth section uses the theory of storage to describe the benefits reflected in the relationship between spot and futures prices. In so doing, conditions in the SO_2 and CO_2 markets are considered. In each section the test is first outlined, data described, SO_2 results shown, and CO_2 results shown. The next section compares these results to findings previously presented in the literature related to the $S0_2$ and $C0_2$ markets respectively. The final section summarizes the set of results and discusses the overall implications.

7.1 Empirical Context

A market for futures contracts is said to be *ideal* if the associated futures forecast provides the best available information at a point in time on the delivery time price of the underlying commodity. Therefore, in the case of $S0_2$ and $C0_2$, the futures forecast should provide the best forecast of the respective permits' spot price at the time of delivery. As noted by Leuthold and Hartman (1979, pg. 482) "… rational price formation becomes a principal economic role for the market because futures prices can provide guidance for decision making and resource allocation." If the pricing information reflected in futures is poor, then it is reasonable to expect a misallocation of resources and ultimately a reduction of economic welfare (Stein 1981).

For purposes of empirical examination this definition implies two main proporeties, whose connections with the two-period expected utility model influence testing choices. The first is that futures should reflect all known permit pricing information. The second is that in modeling the price an economic model must be constructed to express the equilibrium permit prices intertemporally. Both aspects offer empirical applications for testing futures. Tests of futures pricing information will be considered here[69].

Arrow and Debreu (1954) proved that in a complete market there exists an equilibrium in which assets are allocated to their highest value use. At a point in time, an asset's price reflects the discounted sum of future payoffs for alternative state prices

[69] This choice was made for research consistency to maintain themes throughout the chapters. It is recognized that several alternative empirical procedures exist. For example, another approach could have created an intertemporal permit pricing model; however, this approach has two drawbacks. The first is the joint hypothesis problem discussed below. The second is that abatement activities are not expressly considered here and they would have to be a factor in any intertemporal permit pricing model.

(Arrow 1953, Duffie 2008). The different state payoffs are based on the possible resource allocation use values through time, given the economic conditions.

One approach to describe these asset prices is the intertemporal asset pricing model (Breeden 1979, Lucas 1978, Cox, Ingersoll, and Ross 1985). The Lucas (1978) model will be drawn on for discussion. His study develops a model of equilibrium asset prices in a stochastic two period, one-good, pure exchange economy with homogenous consumers. The model is consumption based.

Lucas (1978) found that when prices are in equilibrium, they reflect all available information. His study discusses how this result is consistent with the defining characteristics of market "efficiency". It describes that an implicit assumption in the model -- that expectations of the later period price are rational and, in Fama's term, "fully reflect all available information" (Lucas 1978, pg. 1429).

A general intertemporal asset pricing model can be expressed through the Euler condition as

(7.1) $$p_t = E_t\left(p_{t+1} \frac{\delta U'(C_{t+1})}{U'(C_t)} \right)$$

where p is the asset price, $U'(C_t)$ is the marginal utility of consumption C_t at t, and $0 < \delta < 1$ is a time preference discount factor coefficient. Here the current price can be stated as the expected later price times the pricing kernel (Cochrane 2005). Efficient asset prices are those that reflect this equilibrium at a point in time based on the information set available (Fama 1970, 1991, Cochrane 2005).

In empirical testing of the efficiency of asset prices, a joint hypothesis problem arises in any test of efficiency because the test must assume an equilibrium model that correctly describes the market (Campbell, Lo, and MacKinlay 1997, Fama 1991, Duffie 2008). As noted by Campbell, Lo, and Mackinlay (1997 pg. 24) "if efficiency is rejected, this could be because the market is truly inefficient or because an incorrect equilibrium model has been assumed." To account for the joint hypotheses problem while still allowing for adequate empirical insight, pricing efficiency tests become "conditional "or "relative" efficiency tests defined as informationally efficient in the sense that the capital market fully and correctly reflects all known information in determining asset prices (Fama 1970, 1991, Malkiel 2003, Campbell, Lo, and MacKinlay 1997)[70].

The idea that asset prices are relatively efficient is formally stated as the Efficient Market Hypothesis (EMH) (Fama 1970, 1991, 1998, Malkiel 1973, 2003). The EMH loosely states that in a perfect market with information available at no cost, current prices reflect all available information (Fama 1970, 1991, and 1998, Malkiel1973, 2003). New information that arises randomly is reflected instantaneously in new prices; this process is termed a random walk (Malkiel, 1973, 2003, Campbell, Lo, and MacKinlay 1997). Fama (1970, 1991, and 1998) defines how semi-strong form efficiency can be used to understand the EMH. Semi-strong form efficiency holds that current asset prices are the best estimate at a point in time of later prices and incorporate all publicly available information. The theory holds that in the long run markets are efficient (Malkiel 2003).

The assumption that futures pricing performance is ideal parallels the conditions for semi-strong form efficiency. That is, the futures price reflects all publicly available information. Therefore, semi-strong form futures efficiency tests will be the empirical

[70] Conditional efficiency and relative efficiency are synonyms; however, different research literature references one term vs. the other.

standard. Futures prices are considered semi-strong form efficient if they provide the best available information, at a point in time, on the future spot price of a permit at the time of contract delivery. In futures markets for other commodities, a number of studies have focused on semi-strong form efficiency (Garcia, Leuthold, Fortenbery and Sarassoro 1988, Tomek 1997, Sanders and Manfredo 2005). For further background, Garcia and Leuthold (2004) provide a review of agricultural futures studies and Fama (1991) reviews asset pricing studies. A central theme among all of these tests is that known public information is used to determine if, in fact, the futures prices accurately reflect the information set considered in forecasting later spot prices (Fama 1991).

Much of the analysis in this chapter relies on an understanding of the theory of storage. The theory of storage was previously used describe permit futures in Chapter 5. The theory of storage holds that at any point in time the permit futures price represents the current spot price adjusted for net storage benefits[71]. The net storage benefits from holding an inventory of permits from *t* to *T* is the banking benefit received (inventory value) minus the total inventory storage costs. A firm's banking benefits arise because holding permits can smooth overall production. For both polices examined ($S0_2$ and $C0_2$), a permit's total cost of storage is only the spot price multiplied by the risk free rate of return, reflecting capital costs. No physical costs of storage exist because of the electronic registry characteristics. In this setting, the futures price expectation is

(7.2) $$F_t^{Ti} = E[A_{Ti} | I_t] = E[((1 + r_{t,Ti})s_t - \vartheta_{t,Ti}) | I_t]$$

[71] See Chapter Five section 5.3 for further discussion.

where F_t is the futures price for contract maturity date *Ti* where i = 1,…N is consistent with the contract delivery date. For example, at a given point in time *t*, *T1* refers to the one month ahead futures maturity date and *T3* to the three month ahead futures maturity date, etc. Furthermore, A_{Ti} is the actual (realized) permit spot price at contract maturity *Ti* such that $A_{Ti} = s_{Ti}$, $r_{t,Ti}$ is the risk-free interest rate at *t* spanning the period from *t* to *Ti*, $\vartheta_{t,Ti}$ the net storage benefits at *t* for holding permits to the later date *Ti*, and *I* is the information set available at time *t* (Working 1949, Tomek 1997, Pindyck 2001). This formulation allows evaluation of different futures maturity horizons (*Ti*) at each point in time (t). The risk free rate at a point in time *t*, is the annual risk free rate (Treasury bill rate for US SO_2 and LIBOR for EU CO_2) at *t*, multiplied by the ratio of days the period covers from *t* to *Ti* expressed as $r_{t,Ti} = r_t * (Ti - t)/365$. The net convenience yield can be negative, zero, or positive. The next sections describe the tests used and provide details on specific information tested.

7.2 Granger Causality

In an ideal futures market, new pricing information is instantaneously reflected in prices. For example, if a court issued a ruling on permits that influenced demand, it is expected that for an ideal futures market the futures price adjusts to this new information. To evaluate this condition, I consider whether futures prices reflect information related to permit price changes at the same time or faster than that of spot prices. If futures do not incorporate pricing information at this speed, the presence of an ideal futures market may be in question. In considering the court case example, if new information impacts permits, this should be reflected instantaneously in all the markets it effects (i.e., both spot and futures). Granger causality will be used for this analysis. The remainder of this section describes the Granger causality procedure, the data used in estimation, SO_2 SFI futures results, and CO_2 EUA futures results.

Granger Causality Procedure

Once a vector autoregression (VAR) model is fitted using spot market prices and futures market prices, it can be used to test if one variable "Granger causes" another (Granger 1969). In VAR estimation of a market price *y*, a variable *x* Granger causes y if past values of *x* contain information about changes in *y*. The method has been used to examine lead-lag relationships among spot and futures prices for CO_2 permits from 2008 – 2009 by Chevallier (2010) and during 2008 by Joyeux and Milunovich (2010). Because three separate tests are made, a discussion on the related permit futures literature with these results comes at the end of this chapter. The method has been used to test the lead-lag relationships between spot and futures prices for live cattle (Koontz, Garcia, and Hudson 1990, Oellerman and Farris 1985). It has also been used to examine convenience yield and spot price relationships for copper, heating oil, and lumber in which convenience yield values were found using futures and spot prices (Pindyck 1993). Granger causality has been used to understand basis relationships in pricing between different market locations for corn and soybeans (Manfredo and Sanders 2006, McKenzie 2005, Lewis, Kuethe, Manfredo, Sanders 2012).

A VAR is a model in which *K* variables are specified as linear functions of *p* lags of their own past values and *p* lags of other price series values (Chevallier 2010, Becketti 2013). The spot and futures VAR can be expressed as

(7.3) $$y_t = v + J_1 y_{t-1} + J_2 y_{t-2} + \cdots + J_p y_{t-p} + \varepsilon_t$$

where y_t is a vector of spot $y_{i,t}$ and futures $y_{j,t}$ returns $y_t = \begin{bmatrix} y_{i,t} \\ y_{j,t} \end{bmatrix}$, v is the n-element vector of constants $v = \begin{bmatrix} b^1 \\ b^2, \end{bmatrix}$, J_1 through J_p are 2x2 matrices, and $\varepsilon_t = \begin{bmatrix} \varepsilon_t^1 \\ \varepsilon_t^2 \end{bmatrix}$ is formed of independent random variables following a centered bi-variate normal distribution $N(o, \sum)$ (Chevallier 2010, Becketti 2013). The lag lengths for y_t are represented by p.

The Granger causality test for the VAR $y_{i,t}$ that the futures price does not Granger cause the spot price is a test of the null hypothesis

(7.4) $H_0 : J_1 = J_2 = \cdots = J_p = 0$

(Chevallier 2010, Becketti 2013). If the futures do not Granger cause spot prices, then past futures prices do not contain any statistically significant permit pricing information. The null hypothesis is examined using a Wald test. Rejection of the null hypothesis suggests that the futures market indeed plays a role in determining the spot market price $y_{i,t}$. Rejection of the null hypothesis supports the role of futures as an information source of permit price changes.

The procedure is then reversed to determine if the spot prices Granger cause futures prices $y_{j,t}$. This null hypothesis is again

(7.5) $H_0 : J_1 = J_2 = \cdots = J_p = 0$,

in which case spot prices do not Granger cause futures prices. Rejection of this null hypothesis suggests that the spot market plays a role in the futures market price determination.

Considering the above lead lag relationships, the results can have four possible outcomes as outlined in Table 7.1. The first is that the price is each market Granger causes the other, through rejection of the null hypotheses in (7.4) and (7.5) (result 1 in table 7.1). This would imply that past spot prices and futures prices provide predictive information about price changes and that the two markets have a simultaneous information flow. For purposes of this research, a simultaneous relationship is a positive indication of futures market performance.

The second possibility is that the futures prices Granger cause spot prices but spot prices do not Granger cause futures prices. This result is found through a rejection of the null hypothesis in (7.4) and a failure to reject the null hypothesis in (7.5) (result 2 in table 7.1). This would imply the futures market provides information about permit price changes; however, spot prices do not contain information about futures price changes. Here futures are considered the dominant source of pricing information, an indication of futures market importance, and a positive indication of futures market performance.

The third possible result is a failure to reject the null hypotheses in both (7.4) and (7.5). This would mean that neither past futures prices nor spot prices contain useful predictive information. It is an indication of an inefficient market.

The fourth result is that futures do not Granger cause the spot prices but spot prices do Granger cause futures prices. This would be shown by a failure to reject the null hypothesis in (7.4) and through rejection of the null hypotheses in (7.5). It would suggest that futures do not add permit price change information and that information flow is dominated by spot market information (result 4 in table 7.1).

Table 7.1 Granger Causality Hypothesis Tests

Hypothesis Tests		Null Hypothesis
7.4		Futures prices do not Granger cause spot prices
7.5		Spot prices do not Granger cause futures prices
Result combinations		
1	Rejection of (7.4) and (7.5)	Futures prices Granger causes spot prices Spot prices Granger cause futures prices Simultaneous relationship Supports futures pricing information $Fut \Leftrightarrow Spot$
2	Rejection of only (7.4)	Futures prices Granger cause spot prices Spot prices do not Granger cause futures Futures dominate price change information flow Supports futures pricing information $Fut \rightarrow Spot$
3	A failure to reject (7.4) and (7.5)	Futures prices do not Granger cause spot prices Spot prices do not Granger cause futures prices No useful information flow between markets Does not support futures pricing information
4	Rejection of only (7.5)	Futures prices do not Granger cause spot prices Spot prices Granger cause futures prices Spot prices dominate price change information flow Does not support futures pricing information $Fut \leftarrow Spot$

SO_2 and CO_2 Granger Causality Data and Model Specification

VAR modeling requires a large sample. Because there is less than six years of data on each policy, weekly price series were used for estimation purposes. This is consistent with the related literature which also uses weekly observations (Manfredo and Sanders 2006, Koontz, Garcia, and Hudson 1990). To test futures pricing information, two lag lengths of p are evaluated. The first is that of the optimal VAR model specification in predicting permit prices. Due to the sample size considerations, the maximum lag length was set at six months. The optimal lag length was found by estimating the VAR in equation (7.1) for all lag combinations $p=1, \ldots, 26$ and using the lag structure that minimizes Akaike's Information Criterion (Akaike 1981, Becketti 2013)[72].

The second VAR model specification evaluates the information contained in only the prior week. In estimation of eq. (7.1), *p* is set to 1. This lag length was chosen to test for the influence of immediate price change information.

Estimation in each market requires a permit OTC spot price and futures price. The sources are:

1) *SO_2 over the counter OTC market prices*. The Cantor SO_2 OTC market, listed through BGC Environmental Brokerage Services (formerly CantorCO2e Brokerage), was the primary source of SO_2 spot market data. Daily spot prices from July 2003 - October 2011 and daily transaction volume from 2003-2009 were gathered for the Cantor SO_2 OTC directly from BGC (2012a & b).

2) *SO_2 futures prices*. The Sulfur Financial Instrument (SFI) served as the primary SO_2 futures contract. SFI daily prices, volume, contract maturity date, and open interest for all monthly contracts were gathered from December 2004 – December 2011 as sourced from Bloomberg (2013, 2014).

3) *CO_2 spot market prices*. The Point Carbon CO_2 OTC price is a composite price compiled by Point Carbon. It is the reported permit price used by the European Commission. Daily spot prices from June 18, 2008 – May 2014 were purchased from Point Carbon (2014). Additionally, monthly OTC spot prices for the first trading day of

[72] The AIC criterion is $AIC = -2\ln(L) - 2df$ where *L* is the maximized value of the likelihood function and *df* is the degrees of freedom.

the month for June and July 2014 were gathered from Bloomberg (2014). Volume data was not available through Point Carbon in connection with the composite price.

Point Carbon's OTC price represents a composite of CO_2 OTC markets housed on Bluenext, Climex, the European Energy Exchange, Green Exchange, ICE and Nord Pool from June 2008 – October 2013. The price was compiled as the average of the reported closing prices from each OTC market. Then in October 2013, Point Carbon changed the OTC spot price series to reflect only prices on ICE's OTC because of extremely thin volume on the other OTCs (Point Carbon 2014).

4) *CO_2 futures prices*. The European Union Allowance futures contract served as the primary CO_2 futures. EUA daily prices, volume, contract maturity date, and open interest for all monthly contracts were gathered from July 2008 – July 2014 as sourced from Bloomberg (2013, 2014).

Granger causality for the SO_2 market is tested using weekly price series for the SFI1 futures and Cantor OTC; the series use Wednesday's closing price[73]. The SFI1 futures and Cantor OTC series contain 252 observations each from January 2007 – October 2011.

The weekly data was found to be nonstationary based on the augmented Dickey-Fuller test. To account for the nonstationarity, a first difference was taken and found to be stationary (Table 7.2). This is represented as $(OTC_t - OTC_{t-1})$ and $(Fut_t - Fut_{t-1})$ for each series where t is a weekly period. Additionally, the futures series was corrected for

[73] In the event of missing observations for Wednesday, the prior nearby price was given priority: Tuesday, Monday, Friday, etc.

contract rollover so that each futures contract was differenced from a prior *t-1* value of the same contract[74].

Table 7.2 SO_2 Weekly Price Series Stationarity Tests

Price Series	t-stat	p-value	No. of Obs.
OTC	-1.17	0.69	252
Futures	-1.11	0.71	252
OTC_t-OTC_{t-1}	-15.93	0	251
Fut_t-Fut_{t-1}	-15.34	0	251

Note: The weekly series are used for Granger causality testing

The EU CO_2 market was tested using weekly data for EUA1 futures and the Point Carbon OTC price series. The weekly value uses the Wednesday closing price from each series. Each price series contained 311 observations from June 2008 – May 2014. Both series were found to be stationary (Table 7.3).

Table 7.3 CO_2 Weekly Price Series Stationarity Tests

Price Series	t-stat	p-value	No. of Obs.
OTC	-2.99	0.04	311
Futures	-2.96	0.04	311

Note: The weekly series are used for Granger causality testing

SO_2 Granger Causality Results

The SO_2 Granger causality tests employ first differences of the weekly levels for the SFI1 and OTC series from 2007 through 2011. The optimal VAR lag length specification was shown to be 25 weeks using the AIC criterion (Table 7.4). At this lag length, the futures prices Granger cause spot prices; however, the null hypothesis was only rejected at the ten percent level with a Wald statistic p-value of 0.081. Spot prices did not influence futures prices at this lag length, shown by a failure to reject the null

[74] This means that if the SFI July contract was the weekly series being used, its difference was taken with respect to the prior SFI July contracts value. Then when the SFI August contract was being used, its difference was taken with respect to the prior SFI August contracts value.

hypothesis (Wald statistic p-value 0.116). These results indicate that the SFI futures prices provided information about later permit price changes but the spot prices did not provide information about later futures prices. In this setting, the SFI futures market is the dominant source of pricing information relative to the spot market.

Table 7.4 SO_2 Granger Causality Results

Hypothesis Tests	Nearby VAR (1 week) test statistic	Optimal VAR (25 weeks) test statistic
7.4[1]	0.00***	0.081*
7.5[2]	0.506	0.116
Information Flow	$Fut \rightarrow Spot$	$Fut \rightarrow Spot$

Notes: Price series are in first differences; * indicates the null hypothesis is rejected at the 10% significance level, ** indicates the null hypothesis is rejected at the 5% significance level, and *** indicates the null hypothesis is rejected at the 1% significance level and reported values are the Wald test statistic p-value. [1] Futures prices do not Granger cause spot prices. [2]Spot prices do not Granger cause futures prices. The arrows indicate the information flow found. For example, $Fut \rightarrow Spot$ indicates that futures Granger cause spot prices (futures lead spot).

The second set of results evaluates a lag length of one week. At this lag, the null hypothesis that futures prices do not Granger cause spot prices was rejected at the 1% significance level (Wald statistic p-value 0.00, see Table 7.4). This indicates that SFI futures prices from the previous week provide valuable information in forming spot prices. Alternatively at this horizon, the results indicate that spot prices do not Granger cause futures prices (Wald statistic p-value 0.506). Thus at the one week horizon, SFI futures prices are the dominant source of pricing information between the spot market and futures market.

In summary, both sets of Granger causality results indicate that futures prices are the dominant source of pricing information. Through this role, futures provide information about permit price changes. Further, futures information about price changes was shown to be reflected before that of spot price changes. Based on the two sources of information tested (spot and futures), futures can be said to reflect new pricing information ahead of the spot market. These results imply that participants should look to the SFI futures market for changes in SO_2 permit pricing information. Thus, emission decisions should be based on futures pricing information. These findings are supportive of the $S0_2$ futures market as being "ideal". Relative to other markets (e.g., the spot market examined) the nearby futures contract assimilates price information faster – that is, futures lead the spot market.

CO_2 Granger Causality Results

The Granger causality tests for CO2 s employ the EUA1 futures and spot OTC price series in price levels. Weekly EUA1 futures and spot OTC prices from June 18, 2008 – May 2014 were tested. The results are presented in Table 7.5.

Table 7.5 CO_2 Granger Causality Results

Hypothesis Tests	[1]Nearby and optimal VAR (1 week)
7.4[2]	0.00***
7.5[3]	0.014**
Information flow	$Fut \Leftrightarrow Spot$

Notes:* indicates the null hypothesis is rejected at the 10% significance level, ** indicates the null hypothesis is rejected at the 5% significance level, *** indicates the null hypothesis is rejected at the 1% significance level. [1] The procedures resulted in identical tests discussed further in the text. [2]Futures prices do not Granger cause spot prices. [3]Spot prices do not Granger cause futures prices. $Fut \Leftrightarrow Spot$ indicates a simultaneous relationship between futures and spot prices.
Reported values are the Wald test statistic

Considering lags from one through 26 weeks, the optimal VAR lag length specification was found to be one week using the AIC criterion. Therefore, only the one week horizon was tested for Granger causality. The null hypothesis that futures do not Granger cause spot prices was rejected at the one percent level (Wald test p-value 0.0). Thus, futures prices Granger cause spot prices. The null hypothesis that spot prices

Granger cause futures prices was also rejected but only at the 5 percent significance level (Wald test p-value 0.014). This relationship can be characterized as one of simultaneous information flow between both markets. Therefore, both markets simultaneously reflect information that may impact the $C0_2$ permit market.

Granger Causality Summary

An ideal futures market, in the context of the environmental markets examined here, is based on its ability to form a forward-looking permit price that reflects the best available information on the market-wide incremental cost of controlling the pollutant. Granger causality was used to establish that SFI futures are the dominant source for reflecting price information in comparison to spot prices for U.S. SO_2 permits. In the EU ETS, it was shown that permit price information was simultaneously reflected in EUA futures and spot prices. Both SO_2 and CO_2 results meet the criteria necessary for futures to reflect permit pricing information based on the spot markets and futures markets tested. This indicates that futures markets play an important role in the price discovery process for permits. As a result, an initial criterion for the presence of an ideal futures market is satisfied, in that they reflect information simultaneously (as in the case with the $C0_2$ market) or before the spot market (as in the case of the $S0_2$ market). Thus, for utilities and other entities that use permits in order to comply with emissions standards, these participants may be astute to look to the futures markets for information regarding the future price of the spot permits. The information provided by the futures market may be useful for planning and budgeting purposes as utilities and other users plan their strategies for compliance.

7.3 Futures Performance in Forecasting Subsequent Spot Prices

This section evaluates futures performance in forecasting subsequent permit spot prices. The empirical tests will consider monthly futures forecast horizons to determine (1) if the permit futures price (forecast) at *t* for a contract delivery of permits in *Ti* represents a rational estimate of what the spot permit price will be at the time of contract maturity and (2) if the futures price (forecast) encompasses the predictive information contained in an alternative forecast of delivery time spot prices. First, a framework for testing the two hypotheses is outlined. Then the data are described. The results for the SO_2 futures are then presented, followed by the results for CO_2 futures.

Futures Performance Test Set Up

As discussed at the onset of this chapter, an ideal futures market, in the context of the environmental control markets examined, requires that futures provide the best available information at a point in time on the later spot permit prices for the contract maturity date (Garcia, Leuthold, Fortenbery and Sarassoro, 1988, Tomek 1997, Garcia and Leuthold 2004). For this condition to hold, the futures price must reflect all known information as of the time of estimation. An established necessary condition for considering whether this standard is met is that the futures price must outperform any alternative price forecast generated from the known information at a point in time (Leuthold, Junkus, and Cordier 1989). If the futures are found to outperform an alternative forecast, they are said to be relatively efficient with respect to the information tested. Alternative forecasts previously used in comparisons for other commodities include econometric specifications, time series models, agency forecasts, and expert opinion (Garcia and Leuthold 2004). This necessary condition has been examined for a number of agricultural markets (Rausser and Carter 1983, Garcia et al 1988, Martin and Garcia 1981, Leuthold and Hartmann 1979, Irwin, Gerlow, and Liu 1994, Sanders and Manfredo 2005), energy markets (Ma 1989, Kumar 1992) and financial instruments (Leitch and Tanner 1991, Hafer and Hein 1989). For the most part, these studies find that short time horizon (1-3 month) futures are relatively efficient but there is a degradation of performance as the time to maturity of the associated futures contract increases (Tomek 1997).

One way of testing for this necessary condition is through the mean squared error family of tests. This family includes the mean squared error, root mean squared error, and mean absolute percentage error. In this setting, if the (say) mean squared forecast error resulting from a futures forecast is smaller than a competing forecast's, then the futures-based forecast is said to outperform the competing forecast, meeting the necessary condition for futures market efficiency (specifically semi-strong form market efficiency)

Sanders and Manfredo (2005) demonstrate how focusing on mean squared error only, may leave valuable insights unexplained and can possibly lead to the wrong conclusion regarding market efficiency. In particular they discuss how one forecast may produce a smaller mean squared error than a competitor but still not contain all of the predictive information found in the competing forecast. Sanders and Manfredo (2005) then describe and demonstrate how the forecast encompassing tests of Harvey, Leybourne and Newbold (1997, 1998) and Harvey and Newbold (2000) can be used to evaluate whether futures encompass all of the predictive information contained in an alternative forecast. In doing this, Sanders and Manfredo (2005) demonstrate how forecast encompassing is a more exacting criterion for testing semi-strong form market efficiency in the context of futures markets.

In a separate line of literature, Vuchelen and Gutierrez (2005) develop a test for examining the incremental information contained in forecasts at differing forecast horizons. Their test provides insights into situations where multiple forecasts exist for different time horizons of the same variable. For instance, Vuchelen and Gutierrez (2005) considered how insightful OECD country gross domestic product forecasts were for 6 months, 1 year, and 2 years out. The results allowed insight into if the 2 year out forecast added any value beyond that found in (say) the 1 year forecast. In testing the value between different forecast horizons, the test was also embeds the standard forecast rationality tests (e.g., bias and efficiency). This has led to the testing of futures markets within this framework by Sanders, Garcia, and Manfredo (2008) and Schnake, Karali, and Dorfman (2012).

The modeling approach used here draws on both the encompassing principle and the procedure of Vuchelen and Gutierrez (2005) to understand the futures pricing performance at different time horizons, specifically in comparison to a benchmark forecast. This approach allows for the examination of forecast rationality (bias and efficiency) as well as forecast encompassing. The model can be stated as

(7.6) $$A_{Ti} = \beta_{1Ti} + \beta_{2Ti}(1+r_{t,Ti})s_t + \beta_{3Ti}[F_t^{Ti} - (1+r_{t,Ti})s_t] + e_{ti},$$

where the futures price, F_t^{Ti}, will be considered to be the preferred forecast, A_{Ti} is the realized spot price at *Ti*, the benchmark forecast is represented by $(1+r_{t,Ti})s_t$, *e* is the error term, and *i* corresponds to the selected month horizon.

The benchmark forecast relies on the theory of storage (see section 5.2). It comes from the spot price adjusted by the risk free interest rate as

(7.7) $(1+r_{t,Ti})s_t$

where s_t is the spot price at *t*, and $r_{t,Ti}$ is the risk-free rate over the period *t* to *T*. Noting that the risk-free rate $r_{t,Ti}$ is determined at each observation point in time *t*, it is not assumed to be a constant. The benchmark can be considered to assume a zero net convenience yield. This alternative is used because spot prices adjusted for the risk-free return are known values at time *t.*

Equation (7.6) is made up of three key factors: the actual price (dependent variable), the futures price (preferred forecast), and the alternative (benchmark) forecast. In essence, this is a modification of the Vuchelen and Gutierrez (2005) which allows for evaluating the futures information in comparison to an alternative forecast at each of the distinct time horizons. The appendix (E.1) further outlines the detail behind the original Vuchelen and Gutierrez (2005) test and also describes how this setup can be linked with the encompassing principle.

Two hypotheses are evaluated. The first examines futures forecast rationality following the traditional pricing approach. Rationality is tested through a joint null hypothesis of $\beta_{2i}=\beta_{3i}=1, \beta_{1i}=0$ where $\beta_{1i}=0$ reflects an unbiased estimate of later permit prices and $\beta_{2i}= \beta_{3i}=1$ an efficient forecast (H.1 in Table 7.6)[75]. Rational futures are a positive indication of futures pricing performance.

[75] An unbiased forecast is one which does not systematically over- or underestimate the actual value, while an efficient forecast is one which utilizes all information available at the time of the forecast (Sanders, Manfredo, and Boris 2009).

Table 7.6 Futures Performance Hypothesis Tests Following Equation 7.6

Futures information	Hypothesis tests	Futures support shown by
H.1: F_t^{Ti} Futures are rational forecasts of maturity date permit prices	$\beta_2=\beta_3=1$, $\beta_1=0$	A failure to reject the null hypothesis
H.2: F_t^{Ti} Futures encompass all useful information in spot prices adjusted for capital costs	$\beta_2=\beta_3$	A failure to reject the null hypothesis

The second null hypothesis $\beta_{2i}=\beta_{3i}$, is that the weight ($\beta_{2i} - \beta_{3i}$) on the benchmark forecast $\beta_{2i}(1+r_{t,Ti})s_t$ is zero in an implied composite forecast with futures F_t^{Ti} (H.2 in Table 7.6). A zero weight on the benchmark, $(1+r_{t,Ti})s_t$ in equation (7.6) yields $A_{Ti} = \beta_{1i} + \beta_{3i}F_t^{Ti} + e_{Ti}$. This result and hypothesis test parallels that of the encompassing principle; see the appendix (E.1). Failure to reject the null hypothesis implies that the futures price "encompasses" the competing forecast's predictive information and is relatively efficient. This satisfies a necessary condition for semi-strong form futures market efficiency.

Finally, to evaluate different futures time horizons (e.g., SFI1 month ahead, SFI2 month ahead, and SFI3 month ahead) , eq. (7.6) is separately estimated with *i* values set to identical time periods (months) such that the one month horizon is with *i=1,* the two month with *i=2,* and the five month with *i=5*. For example, the five month (*i=5*) test at *t* uses the futures price for a contract that matures five months after *t*, , considers the risk-free capital costs over the intervening five month period, and uses the realized spot price five months from *t* as the actual value (dependent variable).

SO_2 and CO_2 Pricing Efficiency Data

The sources for the spot prices and futures prices are those previously discussed (the Cantor SO_2 OTC market, the Sulfur Financial Instrument (SFI) futures contract, the Point Carbon CO_2 OTC market, and the European Union Allowance (EUA) futures). The tests are conducted using monthly observations.

Because each permit system is located in a separate region, different interest rates are used. The interest rate sources are:

1) *Treasury-bill rate*. For the U.S. based SO_2 policy, the capital cost of holding a stock of permits is based on the monthly Treasury-bill rate. Monthly T-bill rates from 2007 - 2011 were accessed through the Board of Governors of the Federal Reserve System (2013).

2) LIBOR. For the EU ETS CO_2 system, the LIBOR monthly rate was used. This series spans 2008 – 2014 and was taken from Bloomberg (2014).

The futures series setup for testing the SO_2 market will now be discussed. (In all of the methods the SO_2 market will be used to describe the setup. The identical procedure was used in the CO_2 market.) To examine as many monthly horizons as possible, rolling contract series were constructed to represent *t* period futures that mature one month ahead (SFI1), two months ahead (SFI2),…, five months (SFI5) ahead. In this case, the SFI1 = T1 in the model, etc. The rolling series create observations over time that represent identical time period forecast horizons; this is common practice in futures literature and testing (e.g. Tomek and Gray 1970, Sanders, Garcia, and Manfredo 2009, Schnake, Karali, and Dorfman 2012). Table 7.7 illustrates how futures performance is considered. On July 1, 2007, five separate futures prices series existed for testing. On July 1, 2007, the SFI futures had contracts listed with the following maturity and prices: July 2007- SFI1 $542; August 2007 SFI2 $544; September 2007 SFI3 $546; October 2007 SFI4 $548; November 2007 SFI5 $550. On July 1, 2007, the SFI1 was forecasting a spot price of $544 at maturity on July 26, 2007. Similarly on July 1, 2007, the SFI5 was forecasting a November 27, 2007 spot price of $550.

The table also lists what the maturity date spot price was for each respective horizon, (i.e., the actual price tested). The differences between the July 1, 2007 futures prices and the actual corresponding maturity date prices were SFI1 $12, SFI2 $25, SFI3 $16, SFI4 $6, and SFI5 (-$2). These differences reflect how the forecasted prices can differ from realized prices. As Table 7.7 indicates, each contract has a slightly different maturity date. To account for different contract maturity dates, all time *t* observations are taken on the first trading day of the month. Actual (realized) time period *T* prices are taken on the contract maturity date, which is also the contract's last trading day[76]. The actual price series A_{Ti} used in estimation reflects futures maturity date prices in both the CO_2 and SO_2 markets for consistency.

[76] SFI futures maturity date and last trading day of a particular contract is three business days prior to the last business day of the expiration month. EUA futures maturity date and last trading day is the last Monday of the contract month; however, if the last Monday is a non-business day or there is a non-business day in the four days following the last Monday, the last day of trading will be the penultimate Monday of the delivery month. In futures pricing evaluation use of futures maturity prices is one approach used in the commodity literature (e.g. Fama and French 1987, Pindyck 1993, 2001, 2004, Sanders, Garcia, and Manfredo 2008, Tomek and Gray 1970).

Table 7.7 Snapshot of SFI 1-5 Futures Prices and Realized Values

Futures	SFI1	Jul-07	SFI2	Aug-07	SFI3	Sep-07	SFI4	Oct-07	SFI5	Nov-07
7/1/2007	$542	SFIN7	$544	SFIQ7	$546	SFIU7	548	SFIV7	$550	SFIX7
7/26/2007	$530	M								
8/28/2007			$519	M						
9/25/2007					$530	M				
10/26/2007							542	M		
11/27/2007									$552	M
Difference	$12		$25		$16		$6		-$2	

Note: M means maturity. SFI(letter)(#) represents future contract symbols. Contract maturity is the futures last trading day.

In the SO_2 market, the data allowed estimation of SFI1, SFI2, SFI3, SFI4, and SFI5 month ahead futures series from January 2007 – October 2011 generating a total of 290 observations. The SO_2 market was constrained because active futures trading did not start until 2007 and October 2011 marked the end of active spot and futures trading. In the CO_2 market EUA1, EUA2, and EUA3 month ahead futures series were created from July 2008 – July 2014 data for a total of 216 observations. Monthly EUA futures contracts are only listed three months out; beyond three months, only quarterly contracts are listed. Because of the EUA contract listings, only EUA1-3 month ahead series were available for testing. The series did not start until July 2008 because this was the beginning of available Phase II OTC prices. July 2014 was the last month available at the time of writing.

The actual A_{Ti}, futures forecast F_t^{Ti}, and spot s_t series were tested for stationarity using the augmented Dickey-Fuller test. All of the price series were found to be nonstationary. This resulted in the need to difference each price series, to allow for comparison between the futures forecast and benchmark forecast.

Because each time period represents a unique information set, it is important to compare rates of return over identical information set time intervals. By using log relative rates for identical time intervals for the futures and benchmark forecasts, the scale-free returns between forecasts can be compared over identical time intervals. An advantage to this approach is that the generated returns are scale-free (Campbell, Lo, and MacKinlay 1997). These properties allow for the log normality assumption to avoid issues of limited liability (Campbell, Lo, and MacKinlay 1997). Therefore, incorporating the differencing, equation (7.6) becomes

$$(7.8) \quad \ln\left(\frac{A_{Ti}}{A_{t-1}}\right) = B_1 + B_2 \ln\left(\frac{(1+r_{t,Ti})s_t}{A_{t-1}}\right) + B_3\left[\ln\left(\frac{F_t^{Ti}}{A_{t-1}}\right) - \ln\left(\frac{(1+r_{t,Ti})s_t}{A_{t-1}}\right)\right] + e_t$$

where the notation follows that previously defined. This approach represents one differencing technique used in the economic literature (Campbell, Lo, and MacKinlay 1997, Hansen and Singleton 1982, Cochrane 2005) and is consistent with that of Schnake, Karali, and Dorfman (2012) who use a similar procedure. Equation (7.8) is estimated using OLS, with results presented in tables 7.10 and 7.11 for the SO_2 and CO_2 markets respectively as described below.

Because both the SO_2 and CO_2 markets had a limited number of years available for testing, every separate horizon was made a log relative return from the actual value immediately prior to time t in order to maintain the maximum number of observations. The differenced price series were all found to be stationary using the augmented Dickey-Fuller test; results are reported in Table 7.8 for SO_2 and in Table 7.6 for CO_2.

Table 7.8. SO_2 Monthly Price Series Stationarity Tests, January 2007 - October 2011

Price Series		1 Month	2 Month	3 Month	4 Month	5 Month
OTC	t-stat	-9.342	-4.742	-3.767	-3.637	-2.905
	p-value	0.00	0.00	0.00	0.01	0.04
Futures	t-stat	-9.428	-4.599	-3.725	-3.528	-3.04
	p-value	0.00	0.00	0.00	0.01	0.03
	Implied val.	1	1	2	6	9
	No. of Obs.	57	56	55	54	53

Note: An implied value was constructed for missing observations outlined in (E.2).

Table 7.9 CO_2 Monthly Price Series Stationarity Tests, July 2008 - July 2014

Price Series		1 Month	2 Month	3 Month
OTC	t-stat	-11.209	-4.747	-4.952
	p-value	0.00	0.00	0.00
Futures	t-stat	-11.104	-5.291	-5.06
	p-value	0.00	0.00	0.00
	Implied val.	25	24	25
	No. of Obs.	72	71	70

Note: An implied value was constructed for missing observations outlined in (E.2).

SO_2 Futures Performance Results

The performance of Sulfur Financial Instrument (SFI) futures pricing was evaluated from January 2007 – October 2011. During this time, spot permit prices ranged from $1-694, and SFI1 futures prices traded from $1-720 per permit. The analysis examined the SFI one through five month futures maturity horizons through equation (7.8). The results are based upon monthly observations using the log relative rates of return described above.

The SFI1 – 5 month futures results are presented in Table 7.10. The first column indicates the futures maturity horizon tested. The next three columns present the parameter estimates, with the standard error listed below each coefficient. The first parameter $\beta 1$ is the intercept, the second $\beta 2$ is the slope coefficient associated with the benchmark forecast, and the third $\beta3$ the slope coefficient for the difference between the futures and benchmark forecasts. The fifth column presents the test statistic for the null hypothesis that futures are rational estimates (e.g. unbiased and efficient). The seventh column presents results for the null hypothesis that futures encompass all the useful pricing information contained within the benchmark forecast (see Table 7.6 for a list of the null hypothesis tested). P-values are reported for the null hypotheses parameter restrictions. The 5% significance level was used to determine statistical significance. The last column lists the number of observations tested for each futures maturity horizon.

The failure of to reject the joint null hypothesis $\beta_{2i}=\beta_{3i}=1, \beta_{1i}=0$ for the one month ahead SFI futures (column 5 in Table 7.10) indicates that these futures prices serve as rational forecasts of delivery time spot prices . The test restriction in column six indicates that the futures encompass all of the predictive information contained in spot prices after adjustment for the risk-free rate of return ($\beta_{2T1} = \beta_{3T1}$, p-value = 0.986). It follows that the SFI1 futures are relatively efficient with respect to the information tested, a necessary condition for semi-strong form futures efficiency. Thus, in forming rational estimates of the subsequent one month ahead permit prices, the SFI1 futures offer evidence consistent with an ideal futures market.

Table 7.10 SFI SO_2 Futures Pricing Performance Results

Futures horizon	Parameter β1	β2	β3	Null[a] β2=β3=1, β1=0	Null[a] β2=β3	Obs
SFI 1 month	-0.0717[b]	1.4974	1.4991	0.0543	0.9862	58
	0.0415[c]	0.3302	0.312			
SFI 2 month	-0.1442[b]	1.358	1.4484	0.0024	0.483	57

Table 7.10 (Cont'd) SFI SO_2 Futures Pricing Performance Results

Futures horizon	Parameter β1	β2	β3	Null[a] β2=β3=1, β1=0	Null[a] β2=β3	Obs
SFI 5 month	-0.3698[b]	1.5477	1.8374	0	0.1855	54
	0.0821[c]	0.4081	0.3479			
	0.0561[c]	0.432	0.4082			
SFI 3 month	-0.225[b]	1.4571	1.5841	0.0001	0.4196	56
	0.0687[c]	0.4227	0.3948			
SFI 4 month	-0.3125[b]	1.4027	1.4317	0.0002	0.8709	55
	0.0899[c]	0.4639	0.4438			

Notes: [a] Test statistics represent p-values, a five percent significance level is used.
[b] the variable coefficient values are in this row.
[c] the variable standard errors are in this row.
See Table 7.10 for a list of hypothesis tests.

The SFI2 – 5 month horizons all had similar test results. The null hypothesis of futures rationality was rejected for each of the SFI2 -5 month horizons (column 5). It follows that futures accuracy starts to degrade after one month. If one accepts that the events as discussed in Chapter 3 created a large amount of market uncertainty which affected prices, this result would be expected[77].

At the SFI2- 5 month horizons, the null hypothesis $\beta_{2Ti} = \beta_{3Ti}$ could not be rejected (column 6). This demonstrates that futures encompass all the predictive pricing information contained in the alternative (benchmark) forecast – the spot price adjusted for the risk free return. Because of this, the benchmark forecast cannot be used to generate a

[77] In the sense that these events would led to inaccurate later forecasts. The next section discusses the events in relation to price movements and storage benefits. For example, if in July the futures estimated a price of x for a September maturity, but a court decision with major price affects was released in August, it is reasonable to assume that this July price would no longer be an accurate forecast of the September price.

more accurate forecast relative to that provided by the futures market. . Therefore at the time of estimation, futures are shown to be relatively efficient with respect to the information contained in the benchmark forecast. This indicates all the SFI2 – 5 month futures satisfy a necessary condition for semi-strong form futures efficiency.

The results suggest that the SFI1 month futures can be looked to as rational permit price expectations. However, the SFI2 – 5 month futures were found not to provide rational estimates. However, all the SFI1 – 5 month futures were shown to encompass the information contained within the alternative forecast. The alterative forecast is directly based on the theory of storage and relies on the spot price at the time the forecast is made. This implies the SFI1 -5 month futures are a source of valuable information regarding the market-wide incremental costs of permit compliance. For SO_2 permit compliance, this suggests that futures prices can be used to reduce permit compliance price uncertainty and improve resource allocation.

CO_2Futures Performance Results

The results of the European Union Allowance (EUA) futures are presented in Table (7.11). The time span for the analysis is July 2008 - July 2014. The evaluation examines the EUA1 – 3 month futures maturity horizons. During this time, EUA1 month futures traded between € 2.87 - 29.33 and OTC spot prices between € 2.93 - 28.00. The first column lists the maturity horizon tested. The second through fourth columns list the parameter estimates for the intercept, benchmark forecast, and difference between the futures and benchmark forecast respectively. The standard errors are listed below the respective parameter estimates. The fifth and sixth columns list the p-values for the restrictions tested. The null hypothesis results in the fifth column represent if the futures were rationale estimates. The sixth column presents statistics for the null hypothesis that the futures encompass all the predictive information contained in the benchmark forecast. The final column lists the number of observations at each horizon.

The EUA1 month and EUA 2 month ahead futures were shown to be rational estimates of subsequent permit prices based on a failure to reject the joint null hypothesis of $\beta_{2i}=\beta_{3i}=1, \beta_{1i}=0$ (column 5 in Table 7.11). A failure to reject the joint null hypothesis of $\beta_{2T1}=\beta_{3T1}$ (column 6) indicates that the futures encompass all of the predictive information contained in the alternative forecast. Therefore, the EUA1 and EUA2 month futures are rationale estimates of later permit prices which satisfy a necessary condition for futures efficiency.

Table 7.11 EUA CO_2 Futures Pricing Performance Results

Futures Horizon	Parameter β1	β2	β3	Null[a] β2=β3=1, β1=0	Null[a] β2=β3	Obs
EUA 1 month	-0.0225[b]	0.7217	3.9293	0.1151	0.0702	73
	0.0158[c]	0.1954	1.6936			
EUA 2 month	-0.0486[b]	0.6802	-0.5352	0.0552	0.2470	72
	0.0214[c]	0.2487	1.0413			
EUA 3 month	-0.0738[b]	0.7362	-0.3933	0.0444	0.2665	71
	0.0280[c]	0.3271	1.0261			

Notes: [a] test statistics represent p-values, a five percent significance level is used.
[b] the variable coefficient values are in this row.
[c] the variable standard errors are in this row.
See Table 7.10 for a list of hypothesis tests.

At the EUA3 month horizon, futures rationality was rejected at the 5% level (p-value 0.0444). This indicates that the accuracy of the futures expected rate of return deteriorates as the time horizon increases beyond two months. The EUA3 month futures were still shown to encompass all of the information contained in the spot price adjusted for the risk-free return, $\beta_{2T3} = \beta_{3T3}$ (column 7). This illustrates that the futures were relatively efficient and outperformed the benchmark forecast, a necessary condition for efficiency.

The EUA1 and EUA2 month futures were shown to be rational estimates which encompassed the information tested. Thus, these prices measure the market-wide incremental cost of controlling the pollutant for the 1 and 2 monthly maturity horizons. The EUA3 month horizon futures provide valuable information but are not rational estimates. This suggests that EUA1 – 3 month futures provide valuable information for emission decisions and may be employed as a means to reduce risk through hedging. Further, the rational EUA1 and EU2 month futures suggest that permit compliance risk can be eliminated, thereby allowing risk averse firms to minimize policy compliance costs and improve resource allocation.

7.1 Futures, Spot, and Storage Benefits

The theory of storage will be used to characterize the relationship between futures prices, spot prices, and storage benefits for the SO_2 and CO_2 markets. This section first illustrates how storage benefits are defined based on the theory of storage. Then the data used in estimation is described. This is followed by a section describing the results for the U.S. SO_2 market. Then the EU ETS CO_2 results are presented. Finally, a summary discusses the implications for futures performance.

The theory of storage holds that the net storage benefits from holding an inventory of permits from *t* to *T* is the banking benefit received (inventory value) minus the total inventory storage cost. A firm's banking benefits arise because holding permits allows a firm to smooth production. For both policies examined, a permit's total cost of storage is only the spot price multiplied by the risk free rate of return, reflecting capital costs. No physical costs of storage exist because of the electronic registry characteristics. In this setting and by incorporating the spot and futures relationship, the net convenience yield (net storage benefit) is expressed as

(7.9) $\vartheta_{t,T} = (1 + r_{t,T}) s_t - F_t^T$

where *F* is the futures price for a later maturity date *Ti*, $r_{t,Ti}$ is the risk-free interest rate at *t* spanning the time from *t* to *T, s* the spot (OTC) permit price, and ϑ the net storage benefits (Working 1949, Tomek 1997, Pindyck 2001)[78].

The net convenience yield values can be negative, zero, or positive. A zero net convenience yield value occurs when the storage benefits are equal to the cost of storing permits. Backwardation refers to a net convenience yield greater than zero, which indicates that the market places excess benefits (a premium) on holding permit stocks to avoid potential production disruptions. Backwardation is represented by the spot price + storage costs > futures price, which reflects negative intertemporal spreads (Tomek and Gray 1970, Pindyck 2001). Weak backwardation occurs when the spot price > futures price but less than the storage costs. A market in contango is one with a negative net convenience yield value.

To allow comparison between the SO_2 and CO_2 systems, the convenience yields were expressed as a percentage of the spot price at that point in time as

(7.10) $\%\vartheta_{t,Ti} = (\vartheta_{t,Ti} / s_t)$.

[78] The risk free rate at a point in time *t*, is the annual risk free rate (Tbill for US SO_2 and LIBOR for EU CO_2) at *t*, multiplied by the ratio of days the period covers from *t* to *T* expressed as $r_{t,T} = (T - t)/365 * r_t$.

This allows the net storage benefit to be discussed as a percent of the spot price. Equation (7.10) will be evaluated for each $i=1,\ldots,N$ horizon available at each point in time *t*. By analyzing different monthly horizons, it is possible to determine if storage benefit as a percent of spot prices changes over time.

SO_2 and CO_2 Convenience Yield Data

The sources for the spot prices and futures prices are those previously discussed (the Cantor SO_2 OTC market, the Sulfur Financial Instrument (SFI) futures contract, the U.S. Treasury-bill rate, the Point Carbon CO_2 OTC market, the European Union Allowance (EUA) futures, and the LIBOR rate).

Equation (7.10) was measured using monthly series with each observation taken on the first trading day of a month. The futures series setup for testing the SO_2 market will now be discussed. To examine as many monthly horizons as possible, rolling contract series were constructed to represent *t* period futures that mature one month ahead (SFI1), two months ahead (SFI2),…, five months (SFI5) ahead. An example of how the SFI1-5 month horizon works is presented in Table 7.12. On July 1, 2007, the SFI futures had contracts listed with the following maturity and prices: July 2007-SFI1 $542; August 2007 SFI2 $544; September 2007 SFI3 $546; October 2007 SFI4 $548; November 2007 SFI5 $550. This means that on July 1, 2007, the SFI1 was forecasting a spot price of $542 at maturity on July 26, 2007. Similarly on July 1, 2007, the SFI5 was forecasting a November 27, 2007, spot price of $550.

Table 7.12 Snapshot of SFI 1-5 Months Ahead Futures Price Series

Futures Series	SFI1	SFI2	SFI3	SFI4	SFI5
Prices on 7/1/2007	$542	$544	$546	$548	$550
Months until maturity	1	2	3	4	5
Maturity date	7/26/2007	8/28/2007	9/25/2007	10/26/2007	11/27/2007
Futures contract symbol	SFIN7	SFIQ7	SFIU7	SFIV7	SFIX7

Note: SFI(letter)(#) represents the future contract symbol, the maturity month, and maturity year. Contract maturity is the futures last trading day.

In the SO_2 market, the data allowed estimation of the one thru five month convenience yields from January 2007 – October 2011, generating a total of 290 observations. The SO_2 market was constrained because active futures trading did not start until 2007, and October 2011 marked the end of active spot and futures trading.

In the CO_2 market the one thru three month ahead convenience yields were created from July 2008 – July 2014 data for a total of 216 observations. Monthly EUA futures contracts are only listed three months out; beyond three months, only quarterly contracts are listed. Because of the EUA contract listings, only EUA1-3 month ahead series were available for testing. The series do not start until July 2008 because this was the beginning of available Phase II OTC prices. July 2014 was the last month available at the time of writing for analysis.

SO_2 Futures and Storage Benefit Values

A summary of the net storage benefit results from 2007 to 2011 is presented in Table 7.13. A value of zero means that net storage benefit equals the capital costs associated with holding permits over the time horizon. Over the total sample, 69% of the absolute values were greater than 1%. This result suggests that other benefits to storage were priced into the market. The results also indicate that 64% of the one month, 67% of the two month, 69% of the three month, 71% of the four month, and 74% of the five month values were greater than plus or minus 1% of the spot price. This illustrates that across months as the time horizon expands, net storage benefits deviate from zero more frequently. Loosely, this implies that permit risk increases as the time horizon expands; the risk factors are discussed below.

Table 7.13 SO_2 Convenience Yield (CY) Values 1 - 5 Month Horizons 2007 – 2011

CY horizons	1 month	2 month	3 month	4 month	5 month	Total
Negative CY values	14	14	16	17	18	79
Positive CY values	44	44	42	41	40	211
CY between + and -1%	21	19	18	17	15	90
CY less than < - 5%	3	2	3	3	3	14
CY Value greater than > 5%	25	26	26	26	27	130
Total CY outside + or - 5%	28	28	29	29	30	144
Number of observations	58	58	58	58	58	290

Notes: Monthly convenience yield values from January 2007 - October 2011. The CY% is found in eq. (7.10).

A positive convenience yield means that the market was in backwardation such that intertemporal spreads were negative. In the full sample, backwardation was present at 73% of the SFI1-5 month horizons, with 75% at the one month horizon and a slight decrease to 69% at the five month. Over the period from 2009 – 2011, the average of the one through five month convenience yields in backwardation rose to over 85%.

Two primary sources of risk create these conditions - low levels of inventory and a high degree of market uncertainty (price volatility has been used as a proxy for uncertainty) (Pindyck 2001). Both aspects will be considered.

The permit inventory rose significantly from a bank of 6.9m permits in 2007 to over 16.4m in 2011. In 2007, 9.5m permits were issued against the number needed for compliance of 8.9m. By 2010, issued permits were 8.95m and the annual compliance need was 5.1m. A stocks-to-use ratio defined as ($year_n$ issued permits + $month_{t-1}$ inventory - month emissions) / ($year_n$ total emissions) measures how long the current permit supply would last, based on current demand. This ratio was previously defined in eq. (3.1) and the results over the period considered are reproduced below. Based on the values in Table 7.14, the ratio indicates that permit inventory was never below a six month supply and by 2010 had increased to an over 4.6 year supply[79]. The rapid decline in firm emissions and near constant annual issuance drove the excess supply. In addition, yearly electricity production, which represents the marketed good associated with SO_2 permit compliance, remained relatively constant from 2007 through 2011[80]. This implies that increasing levels of electricity production were not a factor influencing permit demand. Storage benefits (convenience yield) should have been very low or zero based on the permit inventory, permit compliance levels, and yearly electricity production.

Table 7.14 SO_2 Permit Stocks-to-Use Ratios 2000 – 2011

Date	Stocks:use (month)	Stocks:use (year)	Total supply	Issued permits	Permits used
12/1/2006	8.043	0.670	6.300	-	9.4
1/2/2007	20.303	1.692	15.058	9.5	-
12/3/2007	9.303	0.775	6.900	-	8.9
1/2/2008	24.895	2.075	15.767	9.5	-
12/1/2008	13.895	1.158	8.800	-	7.6
1/2/2009	37.526	3.127	17.825	9.5	-
12/1/2009	26.526	2.211	12.600	-	5.7
1/4/2010	49.706	4.142	21.125	8.95	-
12/1/2010	38.706	3.225	16.450	-	5.1
1/3/2011	66.733	5.561	25.025	8.95	-
12/1/2011	55.733	4.644	20.900	-	4.5

Notes: Permits are in millions. Stocks:use ratio equals how long the current supply will last based on the current emission rates.
Source: Own calculations from EPA reports

[79] By comparison, over the last twenty years, the year ending stocks-to-use ratio for corn just before new crop harvest, its lowest yearly point, has only been above 0.30 (just over a three month supply) once. Further, the ending corn stocks-to-use ratio fell below 0.10 (1.2 months supply) five times.
[80] Yearly electricity production was actually about 1% less in 2011 than in 2007, see Table 3.2.

Market uncertainty, described by price volatility, is the second factor associated with causing backwardation. Figure 7.1 graphs the convenience yield values along with the OTC spot prices from 2007 – 2011. The graph illustrates that spot prices were very volatile over the period. They traded from a high of $694 in 2007 to a low of $1.50 by 2011. Similarity SFI1 prices traded from $1 – 720 from 2007 through 2011. Several events may be considered as possible influences on the pricing factors.

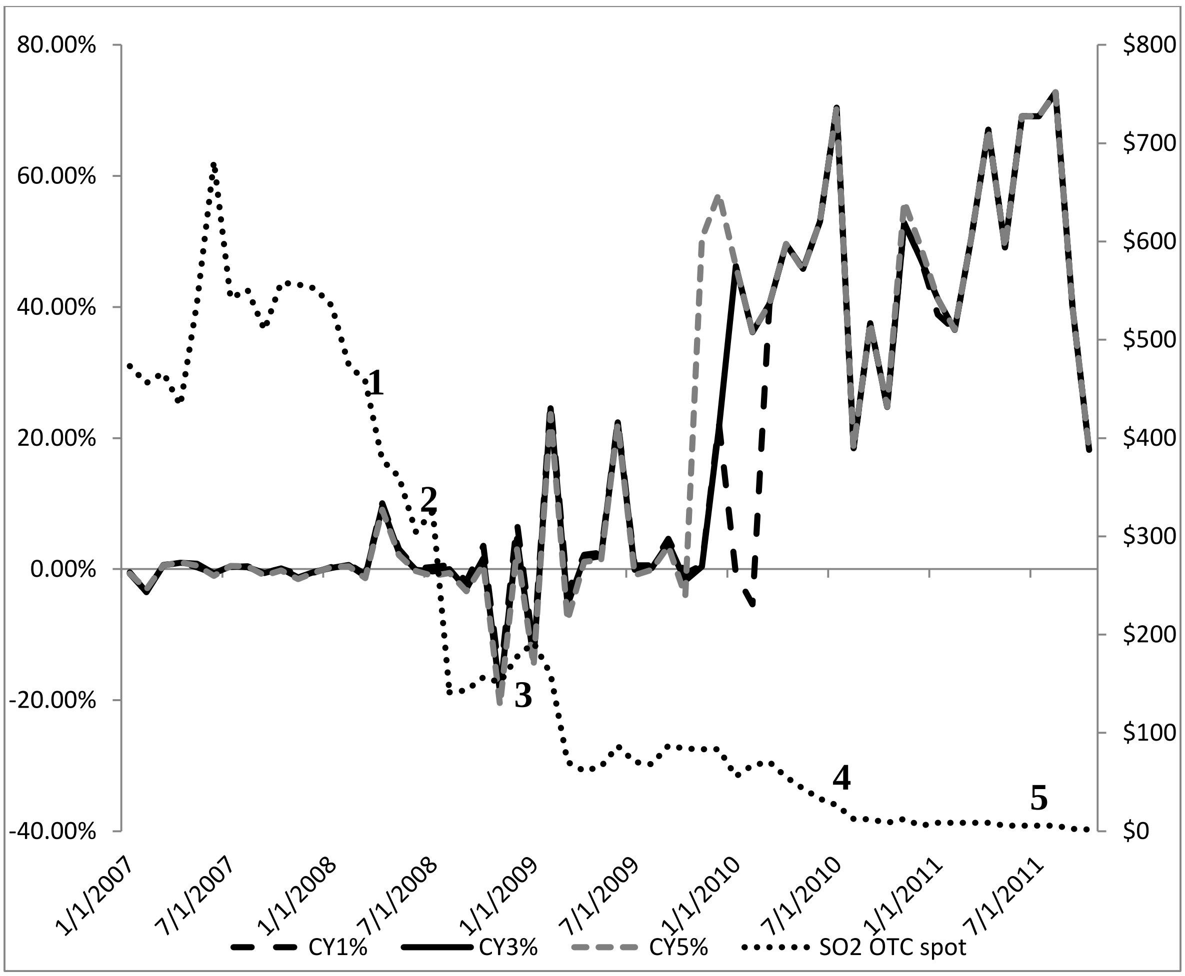

Figure 7.1 Monthly U.S. SO_2 Convenience Yields from January 2007 – October 2011
Notes: CY1% is the one month convenience yield, CY3% the three month, and CY5% the five month. The CY% is found in eq. (7.10) as $\%\vartheta_{t,Ti} = (\vartheta_{t,Ti} / s_t)$.
Numbers - the numbers on the graph refer to events discussed below.

Prior to the evaluation years several policy changes had been proposed which could have altered the initial CAAA law. Foremost was CAIR proposed in 2003. It sought to account for regional concerns by requiring different compliance ratios in various states. From a firm's perspective, CAIR would require tougher emission standards and also an understanding of a complex ratio system that was not uniform across states.

North Carolina challenged the EPA SO_2 regulations in court on June 2006. It argued that the state's ability to meet the National Ambient Air Quality Standards (NAAQS) was inhibited by cross-state SO_2 emissions. The challenge questioned the EPA's authority to implement rule changes and the CAAA system itself. One potential outcome of this court challenge was that CAAA SO_2 permits would no longer be used for electricity regulation; this would make permits worthless. Generally, at the start of the evaluation period in 2007, it can be said that policy uncertainty existed; this uncertainty represented forces that had the potential to make CAAA permits either more valuable or worthless.

During this period, the first major event (number 1 on figure 7.1) was when oral arguments were held on the North Carolina vs EPA case in March 2008. Between the first trading day of March and April, spot prices dropped from $457 to $377 and SFI1 futures from $461 to $340. The one through five month horizon convenience yields at the start of March were all near zero (approx. -1%). By April, all five month horizons had shifted to reflect storage benefits valued at over 9% of permit spot price. This event resulted in a market shift to backwardation reflecting negative intertemporal spreads between spot and futures.

Then on July 11, 2008, the court ruled for North Carolina and vacated CAIR in its entirety, finding that states should be prohibited from damaging other states through cross pollution (see 2 on Figure 7.1). The effect was that net storage benefits returned to approximately zero and prices were relatively flat for a couple of months.

Next on December 23, 2008 (number 3), a court ruling left CAIR and the associated federal implementation plans -- including the CAIR trading programs -- in place until EPA announced the new rule to replace CAIR. This was followed on July 6, 2010 (number 4), by the EPA proposing the Transport Rule to control SO_2. Finally in July 2011 (number 5), implementation of the Cross-State Air Pollution Rule (CSAPR) occurred. While these last three events were occurring, net storage benefits represented backwardation in excess of 5% of the spot price in 71% of the observations (125 of 175). This was a dramatic change from the time period prior to December 2008.

This suggests that market backwardation was not driven by low levels of inventory (fear of stock outs). Rather, it was caused by policy uncertainty regarding potential rule changes and court cases. For instance in anticipation of a new rule requiring firms to use 4 permits for every unit of emissions (essentially a more stringent standard), it is reasonable that firms may have wished to hold an excess permit inventory to hedge against the risk of stricter compliance rules.

Regardless of the cause, backwardation implied that the market perceived some type of risk through its willingness to accept a negative return from holding permits over an extended period. These relationships suggest that futures prices are likely to provide information about net storage benefits.

CO_2 Futures and Storage Benefit Values

The EU ETS CO_2 convenience yield values expressed through eq. (7.10) were estimated at the one, two, and three month horizons. A summary of the values are presented in Table 7.15. Figure 7.2 presents the one, two, and three month convenience yields along with the spot prices from July 2008 – July 2014. The results indicate that the absolute value of the percentage convenience yield values were very close to zero. For the one to three month horizons, 63% of the 219 observations were within 1% and over 95% of the total were within 5% of zero. Thus, these values indicate that no excess storage benefits existed.

Table 7.15 CO_2 Convenience Yield (CY) Values, July 2008 - July 2014

CY horizons	1 month	2 month	3 month	Total
Negative CY values	42	39	43	124
Positive CY values	31	33	29	93
CY between + and -1%	57	43	38	138
CY less than < - 5%	0	1	1	2
CY Value greater than > 5%	0	1	6	7
Total CY outside + or - 5%	0	2	7	9
Number of observations	73	73	73	219

Notes: Monthly convenience yield values from January 2007 - October 2011. The CY% is found in eq. (7.10).

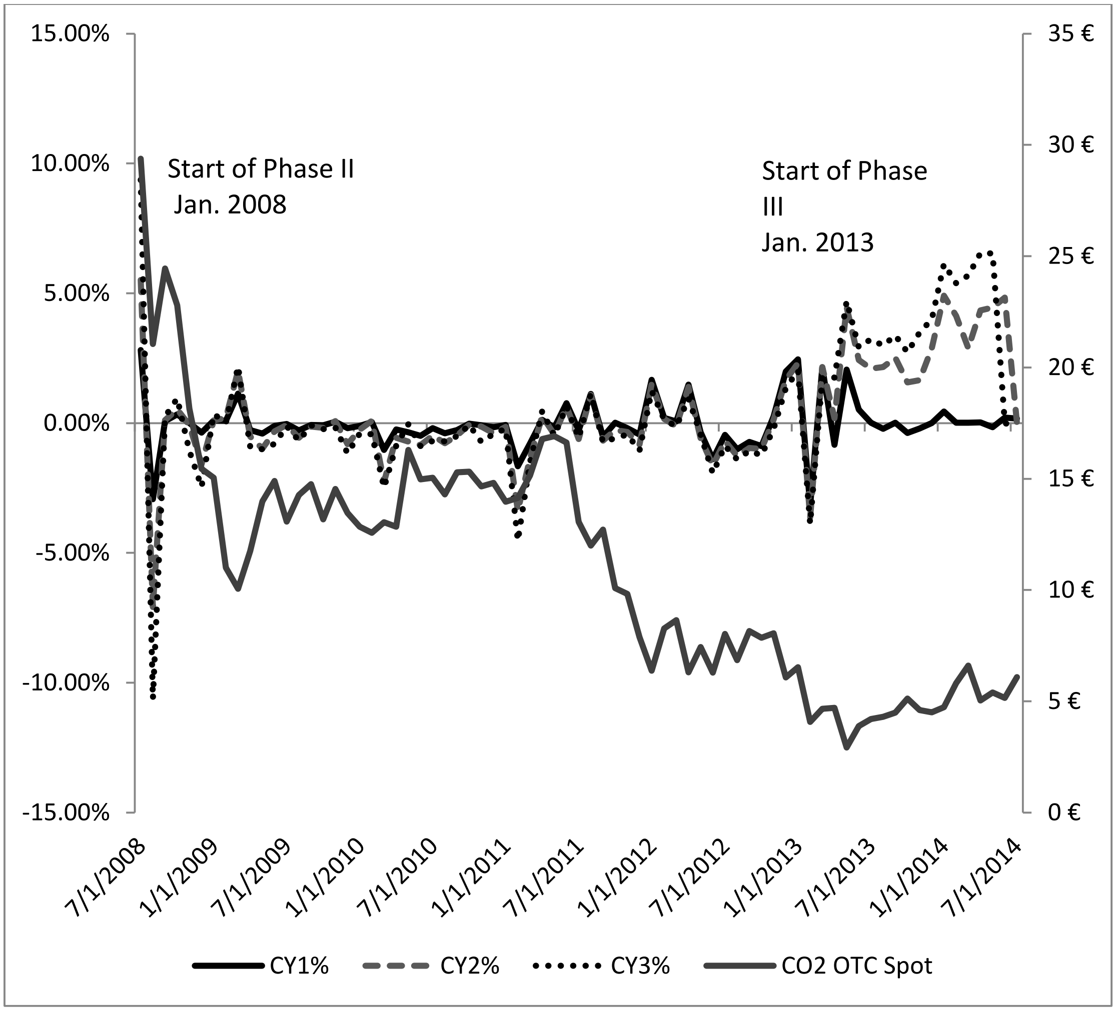

Figure 7.2 EU CO_2 Convenience Yields July 2008 - July 2014
Notes: CY1% is the one month convenience yield, CY2% the two month, and CY3% the three month.

The convenience yield measures imply 1) that the market believed there was an adequate supply of permits to meet compliance requirements and 2) that policy uncertainty did not give rise to storage values in excess of the capital costs of holding inventory.

For the EU ETS, permit supply factors include issued permits, permits used in compliance, and created permits from international emission reduction credits. The permit inventory was zero at the start of 2008 because that was the first year of permit availability. From 2008 on, inventories grew steadily, reaching more than 2,100m permits by 2014 (EC 2014b). In 2013, 1,895m permits were used in compliance. This resulted in a stocks-to-use ratio of over 1.1 years.

EC reports suggest that increased inventory was created by two factors. The first was that more permits were issued than used in compliance. For example in the first year of Phase III (2013), 2,084m permits were issued and 1,896m used in compliance (EC 2014b). Similarly in the last year of Phase II (2012), 2,229m permits were issued and 1,950m were used. These years are representative of all years over 2008 – 2014. As a result, the discrepancy between yearly issuance and compliance increased supply.

The second supply/inventory factor is that international emission reduction credits can be created by firms to act as an outside supply source. The credits can be created in two forms in accordance with the EU ETS and Kyoto Protocol rules. The first is certified emission reductions (CERs) arising from emission reduction projects in developing countries. The second is as emission reduction units (ERUs) created from emission reduction projects in industrialized countries. The CER's and ERU's create a source of permits and uncertainty that is independent of the issuing of CO_2 permits. Their supply flow can come on-line any time during a year and does not alter the previously defined number of regular CO_2 permits to be issued. From 2008 - 2012, the market made use of these credits through creation of over 1,047m CERs and ERUs. This represented 9.7% of all verified permits through 2012 and highlights the fact that both CERs and ERUs have been used to create a large number of permits. Given the large number of CER and ERU projects, it is reasonable to expect their continued project use as an exogenous factor. It follows that they would be expected to add to the permit supply as an independent source.

This secondary supply source could potentially serve to reduce market uncertainty. For instance if CO_2 permit prices rise sharply because of greater demand, new ERU and CER projects can be undertaken. These additional ERU and CER credits could then be sold at the higher permit price levels which would result in an influx of new CO_2 credits. Another relevant factor is that these credits can only add to the permit supply (i.e., under no rules can they decrease available permits). This suggests that CER and ERU credits serve to potentially limit worries about low permit supply.

The broad policy and rules outlining CO_2 permit issuance and compliance are known. Phase III runs through 2020, and the recently passed extensions run until 2030. However, new rule changes are currently being discussed that may alter the level of permits issued. These rules would still be based within the broad EU ETS framework, but the individual EU27 countries must agree to any rule changes. One possibility to consider is that new rules that would drastically reduce permit supply may not have a high probability of approval.

With the EU ETS in place through 2030, I expect that more permits will be issued yearly (auctions and endowments) than will be used in compliance, as is currently the case. This would further increase permit inventories. If so, zero or near zero net storage benefits are appropriate. It follows that CO_2 futures may not incorporate unique storage benefit information because the values are approximately zero.

Summary of Futures and Storage Benefits Values

Positive net storage values were found for the U.S. SO_2 and EU ETS CO_2 permit systems. The SO_2 results illustrated the presence of storage benefits in excess of capital costs. Market conditions imply that this was caused by policy uncertainty which can be linked to events that affected spot prices, futures prices, and storage values. In contrast, the CO_2 market was found to have storage benefits equal to the capital costs of holding permits. In both markets, the relationship between spot, futures, and storage benefits illustrates that the presence of a futures market offers firms a means to form emission decisions and lock in compliance costs through time.

7.5 Related SO_2 and CO_2 Futures Literature

The results provided in the previous section are now considered relative to existing literature on SO_2 and CO_2 futures. To my knowledge, no literature exists on the SO_2 market that shows empirical connections for futures use by regulated firms as a means to eliminate permit price uncertainty effects on production of the marketed good. Within the empirical studies surprisingly little is known regarding the pricing efficiency of the Sulfur Financial Instrument futures for SO_2 permits in general. There is a rich literature surrounding the empirical examination of CO_2 futures pricing efficiency.

SO_2 SFI futures literature

One of the few, if only, studies to specifically examine SFI permit futures markets was that of Boutaba (2009). The study tests the relationship between nine December SFI future contracts (the December futures contracts for 2006 through 2014) against the Chicago Climate Futures Exchange (CCFE) over the counter (OTC) spot market. The study used daily prices from December 10, 2004, through August 29, 2008. Due to nonstationarity in the price series, Boutaba used an error correction model to test the long run relationship between the nine futures contracts and spot prices. The findings for all nine of the December futures contracts reject the joint null hypothesis of efficiency; the tested restrictions are that the futures are 1) unbiased –zero intercept, 2) rational – futures coefficient of 1, and 3) that the error correction term deviates from the long-term relationship of the spot and futures (Boutaba 2009, Table 5 pg. 8). This approach is similar to that used by Carter and Mohapatra (2008) who examined the efficiency of lean hog futures. Boutaba (2009, pg. 8) concludes that "these results strongly suggest that there are short-run deviations from the long-run efficiency conditions and therefore the existence of short-run inefficiency".

In sum, the results here for the SFI futures suggest that futures served a valuable role in providing information from 2007 – 2011. This research finds support for the idea that futures efficiently incorporate information contained in spot prices, adjusted for carrying costs, for SFI 1 – 5 month horizons from 2007 - 2011. However, only the SFI1 month horizon was rational. It also finds, in a VAR setting using Granger causality, that nearby futures are the dominant source of price change information. In comparison, the Boutaba (2009) study found that nine SFI December contracts for 2006 – 2014 were inefficient based on their cointegrating relationship with spot prices from December 2004 – August 2008.

Three differences may explain the markedly different findings. The first is that this research evaluated time horizons with a maximum length of 5 months. Boutaba considered SFI contracts whose initial maturity was over two years. Taken together, the two studies suggest that as the time horizon increases, futures performance deteriorates. The second difference is that my research covered 2007 – 2011 whereas Boutaba covered December 2004 – August 2008. Therefore, the price series considered in the two studies covered different time ranges. A possible consideration, as discussed in Chapter 3, is that the SFI futures volume was not sufficient to form an active futures market until 2007. A very thin market is commonly characterized by inefficiencies. It would be interesting to reexamine the Boutaba study through 2011.

The third difference may arise from a potential drawback of the Boutaba study that may affect comparisons to this research. While the error correction method is consistent with the related studies, its use in examining futures contracts that had not matured is slightly different. The SFI contracts I tested were the December contracts for 2006-2014. The daily price series only span December 10, 2004, through August 29, 2008. By August 29, 2008, seven of the nine contracts tested had not matured (SFI December 2008 – 2014). It follows that futures convergence to SO_2 permits did not take place for these seven contracts. If a contract has not matured, the long run temporal relationship between the spot and futures markets has not been fully identified. Because error correction models specifically examine the lagged long run equilibrium between spot and futures as a test restriction, this data limitation could affect the results. This, in turn, may restrict the testable contracts to those that have matured. If only the results for matured contracts are considered, then the only two contract available for interpretation, the SFIZ 06 and SFIZ 07.

CO_2 EUA Futures Literature

The empirical literature examining CO_2 Phase I and Phase II spot market, futures market, and pricing factors is voluminous, covering many modeling techniques. It includes Alberola and Chevallier (2009), Alberola, Chevallier, and Chèze (2008), Bunn and Fezzi (2008), Christiansen et. al. (2005), Chevallier (2010), Frunza, Guegan, and Thiebaut (2010), Joyeux and Milunovich (2010), Kanen (2006), Nazifi (2010, 2013), Rickels, Görlich, and Oberst (2010), and Venmans (2012). Overall, the findings suggest that CO_2 Phase I permit pricing was inefficient (Alberola, and Chevallier 2009, Chevallier, Ielpo, and Mercier 2009, Hintermann 2010). The results also indicate that in March of 2006 when the first report of total emissions used in compliance was released, a large information gap existed which led to a structural break in the market (price fell dramatically at this time). This led the unit permit price to go from over €25 to under €5 within a year. By the end of Phase I, permits were trading below €1 as the large supply expired worthless.

Phase I did establish many important market aspects and information useful for forming the market in Phase II. The Phase I literature examined fundamental price drivers of marginal abatement costs and permit prices. These studies found limited support for permit prices being related to expected abatement factors such as coal, natural gas, and weather (Alberola, Chevallier, and Chèze 2008, Bunn and Fezzi 2008, Hintermann 2010). Studies also considered the stochastic behavior of permit prices and emissions during Phase I (Rickels, Duscha, Keller, and Peterson 2007, Chesney and Taschini 2012, Hintermann 2012). Of these, Hintermann (2012) found that permit prices are largely explained without relying on abatement cost drivers. His study concluded that firms were hedging against the possible noncompliance penalty. It also determined that uncertainty about future emissions was itself a key price driver (Hintermann 2012). This literature supports the notion that permit prices are uncertain. What is required for futures to be able to mitigate risk is that they offer the best available information on later compliance costs. If futures are efficient, futures provide a useful tool that firms can employ to eliminate permit price variability through hedging.

CO_2 Phase II futures pricing performance results are mixed and vary by years examined. In the initial policy years (2008 and 2009) the mixed results slightly suggest market inefficiency. Studies covering later policy years support the notion that the market has become relatively efficient (e.g., Daskalakis 2013). This may reflect learning by doing, in that as firms become accustomed to compliance, their knowledge and understanding increase.

In comparison to the tests used in this dissertation, Granger causality between spot and futures has been examined by Joyeux and Milunovich (2010) for 2008 and by Chevallier (2010) for 2008 - 2009. Their findings suggest that futures play an important role in permit trading and price discovery. Chevallier tested the relationship between spot prices on Bluenext OTC and futures from the European Climate Exchange. Her study used a vector error correction model to demonstrate the existence of a cointegrating relationship between spot and futures and that the lagged values of each respective market price explained the corresponding price movement. Chevallier also tested for Granger causality using a VAR specification. The results indicate that futures cause spot price movements but that spot prices do not cause futures price movements. The results in this dissertation indicated a simultaneous relationship between spot and futures which is supportive for futures as a source of price change information. This dissertation and the studies of Joyeux and Milunovich (2010) and Chevallier (2010) using Granger causality all indicate that futures play an important role in the price discovery process.

A recent paper by Daskalakis (2013) using EUA futures examined futures pricing efficiency overs the years 2008 - 2011 (the paper represents the longest time span covered by Phase II at the time of this writing). He used three trading rules to determine if technical analysis could be used to exploit the market; a finding of trading profits could be used to reject market efficiency. The study concluded that futures were efficient from 2010 onwards (i.e., no trading profits were found for 2010 and 2011 (Daskalakis 2013). A prior study by Montagnoli and de Vries (2010) used variance ratio tests of the BlueNext exchange to find that, after inefficiencies in Phase I and at the start of Phase II (2005 – 2008), permit price traits reflected those of an efficient market by the end of 2009.

The permit spot and futures relationship via convenience yield measurements has been used to find that the Phase II market was efficient by 2012 as well (Trück, Hardle, and Weron 2014). Their study covered the Phase II years from 2008 – 2012 (it is the most recent on convenience yields at the time of writing). This study was the first to consider all of the Phase II policy years. It used data from Point Carbon which reflects futures prices for the EUA and spot prices for European Energy Exchange. For convenience yield measurements the study considered the difference between spot prices and single futures contract prices over the contract's life (spot vs. EUA Dec 2010, spot vs. EUA Dec 2012, and spot vs. EUA Dec 2014). They also tested the correlation between the spot and futures contracts. The findings indicate that the correlation coefficients between spot prices and different futures prices were always above 0.95 and very close to 1 (Trück, Hardle, and Weron 2014).

Trück, Hardle, and Weron (2014) found that after a brief period of backwardation during 2008, the market moved into near zero or negative convenience yield values (contango) from 2009 onwards. They also determined that as the futures contract maturity approached, storage benefits moved closer to zero. Their study adjusted the risk free rate based on the European Central Bank's AAA government bonds. By adjusting the risk free rate, their study differs from the past convenience yield work by Madaleno and Pinho (2011), Chang, Wang, Peng (2013), and Gorenflo (2013). However, their results generally still match the prior studies. The only difference in Trück, Hardle, and Weron 2014 compared to the others is that their convenience yield values are negative form 2009 onwards. Trück, Hardle, and Weron (2014) note that this difference in results is probably caused by the constant risk free rate used in the prior studies being much higher than the rates from 2009 on (which were approximately 1%).

Currently there is a large body of diverse tests covering futures performance for the EU ETS. The efficiency procedures used here add to the literature by extending the years examined and by taking a different vantage point. By using set time horizons, the separate one through three month ahead decisions can be considered. Using the theory of storage to construct an alternative forecast offers a direct way to measure specific sources of futures pricing information. The results support futures prices as an information source to inform decision making over one to three month horizons. Support was also provided for the role of nearby weekly futures in the price discovery process. These findings are consistent with recent papers which find that the EUA futures are efficient.

7.6 Summary

Futures prices in the U.S. SO_2 and EU ETS CO_2 permit systems were tested for evidence consistent with the presence of an ideal futures market. Ideal futures prices are those that provide the best available information at a point in time on the market-wide incremental cost of controlling the pollutant at the contract maturity date. First, the ability of futures prices to reflect changes in permit pricing information was examined.

Then the ability of futures prices to forecast later permit prices was tested. Finally, the theory of storage was used to describe permit market and futures market conditions. Overall, the findings offer evidence consistent with an ideal futures market, given the information tested.

SFI futures were examined from 2007 through 2011. They were shown to be the dominant source of price change information over the spot market for SO_2 permits. In forecasting permit prices, the SFI1 month futures were rational estimates which encompassed all the pricing information contained in an (alternative) benchmark forecast formed from spot prices adjusted for capital costs. The SFI2 – 5 month futures were also found to encompass all the information in the alternative forecast. By outperforming the alternative forecast, the SFI1 – 5 month futures satisfy a necessary condition for semi-strong form efficiency. However, futures accuracy deteriorates as the time horizon increases beyond one month.

The theory of storage described how the permit market placed excess storage benefits on permits through the spot and futures price relationship over the one to five month horizons. It was suggested that the extreme amount of policy uncertainty present in the marketplace, which ultimately led to the end of SO_2 regulations as created in the CAAA, was the cause of these storage conditions. This policy uncertainty may also have been a factor leading to the deterioration of futures forecasting performance as the time horizon increased. The tests used here indicate support consistent with an ideal futures market for SO_2 permits.

The EUA futures were evaluated from 2008 – 2014. The futures were shown to have a simultaneous information flow with the spot market. Both of the EUA1 and

EUA2 month futures were found to be rational estimates of later permit prices and encompass the information contained in the alternative forecast. However, the EUA3 month futures were only shown to outperform the benchmark forecast. Overall, support is shown for the idea that EUA1-3 month futures provide valuable information on the later market-wide incremental costs of controlling CO_2. The conditions found through the theory of storage implied that the market had an ample supply of permits and little policy uncertainty existed.

These tests were used as a framework to describe market conditions and test for the presence of an ideal futures market, which is a maintained assumption of the expected utility model. While informative for this focus, the results only indicate consistency – a necessary but not a sufficient condition -- with an ideal futures market. As discussed at the outset, pricing performance should be based on use of the best available information. Several alternative information tests exist which can provide further insight into the question of whether an ideal futures market exists. For instance, arbitrage conditions could be examined, trading rules tested, or several alternative permit forecasts created in addition to the benchmark used which relies strictly on the theory of storage (e.g., forecasts generated from an econometric model of permit spot prices; a time series model of past permit prices; expert opinion forecasts; etc.). Therefore, these results can be viewed as providing insight into specific areas related to this determination. They are not definitive conclusions.

To summarize, the SFI futures and EUA futures results resemble the pricing performance of other storable commodity markets (e.g. Fama and French 1987, Garcia and Leuthold 2004, Tomek 1997). For example, Fama and French (1987) found that oats, soybeans, and soymeal futures had good predictive performance in estimating later spot prices and followed the theory of storage in forming prices. In the cases of SFI and EUA futures, outperforming the alternative forecasts, being rational estimates in the very near term, and reflecting new pricing information all suggest that futures prices are consistent with what would be expected of an ideal futures market. This implies the SFI1 – 5 month and EUA1 – 3 month futures can be looked to for the best information on the market-wide incremental costs of pollutant control at a point in time. The use of futures prices when making emission decisions can eliminate the negative effects of permit price risk. In turn this implies firms can use SO_2 and CO_2 futures to minimize permit policy compliance costs and improve resource allocation. The next chapter summarizes the discussion and results considered in this dissertation.

CHAPTER 8

CONCLUSIONS AND FUTURE RESERCH

This dissertation has studied the ability of futures markets in permits to enhance permit systems performance in the presence of permit price uncertainty. Because policymakers must select regulatory action without complete cost information, understanding how different dimensions of uncertainty may affect policy performance is an important research topic.

It was first shown how permit price uncertainty can be described in an expected utility framework. The setting considered a firm that produces both a marketable good (e.g., electricity) and the associated emissions that are regulated through the use of permits. At the time of the production decision, uncertainty was assumed regarding both the marketable good's final price and the permit price. In the absence of a futures market, permit price uncertainty would imply that risk averse firms make output adjustments as part of their response to this uncertainty. In this setting, a firm's policy compliance costs would then reflect both the permit price and the effects of risk aversion. For a set permit quantity, this suggests that firm policy costs are higher than under conditions of certainty.

Futures markets were then introduced as an alternative permit pricing mechanism. The results demonstrated that the futures price reflects the marginal cost of compliance from using permits to meet regulatory emissions standards. If there is no uncertainty about the futures price, production is not affected by a firm's risk aversion or changes in expectations regarding the unknown later period permit price. By hedging with futures, firms can eliminate the price uncertainty associated with later permit purchases.

Furthermore, under the assumption that all firms optimally hedge, the theoretical model showed that futures' hedging allows firms to maintain supply of the marketed good at the cost minimizing level, thereby separating the output production decision from the emissions compliance decision.

The theoretical results assume that futures prices provide firms the best available information on the market-wide incremental costs of permit compliance. To understand if real-world futures prices contain aspects of the information necessary for the theoretical results to hold, the Sulfur Financial Instrument (SFI) futures market for SO_2 permits and European Union Allowance (EUA) futures market for CO_2 permits were empirically evaluated. Consistent with an ideal futures market, it was shown that futures in both markets reflect changes in permit pricing information. Evidence from both markets supports the assumption that futures encompass the predictive information contained in spot prices adjusted for carrying costs. Then, the theory of storage was used to characterize how futures were able to convey this information within very different policy markets. Overall these information tests suggest that futures prices offer a window into the marginal cost of compliance associated with using permits.

Future research needs to consider the connection between futures markets and abatement activities. This topic needs to be explored because reducing emission levels is a core policy goal. The theoretical model used here assumes a one-to-one linkage between output and emissions. Abatement activity can change this relationship. For example, abatement activities could involve new production technologies for the marketed good, building new plants, or retrofitting existing plants with better emission control technologies. An implication of these results is that the futures price could serve as the price signal to harmonize abatement activities among firms. A second consideration is that certain abatement activities can involve a long time horizon, such as investing in research and development of new technologies. If futures contracts with distant maturity horizons became available, long-term abatement pricing information and hedging of risk may become possible.

A second topic for future research would be examining the impact of certain events or possible structural change to determine if futures performance was consistent through time and across a futures contract series. While the empirical results in this paper suggest that the futures performed reasonably well for both markets over the same period, it may be the case that the futures perform differently over certain periods surrounding policy changes. Considering that proposed rule changes, new laws, and court rulings likely contribute to price volatility, this topic should be examined further. Specifically a futures contract series offers the opportunity to evaluate whether different risk premiums exist. If different risk premiums exist, they may be used to understand events, anticipated rule changes, and structural changes in permit markets.

This dissertation provides a framework for understanding the role of futures markets in permit systems. By offering a competitive market with a constellation of prices through time, futures can facilitate price discovery, hedge compliance risk, smooth inventory allocation, and reflect the market-wide incremental costs of permit compliance. Policymakers, environmental advocates, and industry groups should be aware of futures contracts and consider how the rules governing permit structure, exchange and banking affect the ability to sustain markets in futures contracts as well as the likely performance of the markets in permits.

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APPENDIX A

DERIVATION OF CHAPTER TWO EQUATIONS

The appendix is numbered such that a section or equation corresponds to the text reference (A.#). Any equation written as (#) corresponds to its place in the main body of text. In the appendix, derivations (letters) are used to denote equations used in solving for the appendix value.

(A.1) The firm's maximization expressed in terms of *y* in (2.4).

$$Max_{H,y,z}\{EU(w+py-q(z-\zeta)+(\psi-F)H)-Min_{x}\{v'x:\ y=f(x)\}:\ z=g(y)\}$$

$$Max_{H,y,z}\{EU(w+py-q(z-\zeta)+(\psi-F)H-C(v',y):\ z=g(y)\}$$

$$Max_{H,y}\{EU(w+py+q\zeta+(\psi-F)H-C(v',y)+Max_{z}\{-qz:\ z=g(y)\}\}$$

(A.2) Forming equation (2.6) based on expectations of *p* and *q* for rewriting (2.6), output prices are

$$E[U'p]=Cov(U',p)+E[U']E[p]$$
$$E[U'p]=Cov(U',p)+E[U']\mu$$

$$\begin{aligned}Cov(U',p)&=E[U'p]-E[U']E[p]\\&=E[U'\cdot(\mu+\sigma e)]-E[U']E[\mu+\sigma e]\\Cov(U',p)&=E[U'\sigma e]\end{aligned}$$

and permit prices are

$$E[-U'qg']=Cov(U',-qg')+E[U']E[-qg']$$
$$E[-U'qg']=Cov(U',-qg')-E[U']\eta g'$$
$$-g'E[U'q]=-g'Cov(U',q)-E[U']\eta g'$$

$$\begin{aligned}Cov(U',-qg')&=E[-U'qg']+E[U']E[-qg']\\&=E[-g'U'\cdot(\eta+\lambda\varepsilon)]-E[U']E[(-g')(\eta+\lambda\varepsilon)]\\&=-g'\eta E(U')-g'E[U'\lambda\varepsilon]+g'\eta E[U']\\Cov(U',-qg')&=-g'E[U'\lambda\varepsilon]\end{aligned}$$

(2.4) then can be stated as

$$\frac{\partial EU}{\partial y}:\ \ E[U']\mu - E[U']\eta g' - E[U']C' + Cov(U', p) + Cov(U', -qg') = 0$$

and simplifies to

(2.6) $$\frac{\partial EU}{\partial y}:\ \ \mu - \eta g' = C' + \frac{g' Cov(U', q) - Cov(U', p)}{E(U')} = 0$$

(A.3) Forming the risk premium of (2.8)

The firm's risk premium is found by combining two Taylor series expansions. A second order Taylor series expansion of $U(w + py - q(g(y) - \zeta) - C(v', y))$ in the neighborhood of $[w + E(py - q(g(y) - \zeta) - C(v', y))]$ can be expressed as

(a) $$\begin{aligned} U(w+\pi) &\approx EU[(w + E(py - q(g(y) - \zeta) - C(v', y)) \\ &+ U' \cdot E[(w + py - q(g(y) - \zeta) - C(v', y)) - (w + E(py - q(g(y) - \zeta) - C(v', y))] \\ &+ \frac{U''}{2} \cdot E[(w + py - q(g(y) - \zeta) - C(v', y)) - (w + E(py - q(g(y) - \zeta) - C(v', y))]^2 \end{aligned}$$

where $U' = \partial U / \partial w$ is the first derivative of the utility function, and $U'' = \partial^2 U / \partial w^2$ is the second derivative, each evaluated at $(w + E(\pi))$. After taking the expectation, separated into parts, the middle term is

$$\begin{aligned} & U' \cdot E[(w + py - q(g(y) - \zeta) - C(v', y)) - (w + E(py - q(g(y) - \zeta) - C(v', y))] \\ &= U' \cdot E[(py - qg(y) + q\zeta) - C(v', y)) - (E(py) - E(qg(y)) + E(q\zeta) - E(C(v', y))] \\ &= U' \cdot [E(py) - E(qg(y)) + E(q\zeta) - E(C(v', y)) - E(py) + E(qg(y)) - E(q\zeta) + E(C(v', y))] \\ &= 0 \end{aligned}$$

The last term is

$$\frac{U''}{2}\cdot E[(w+py-qg(y)+q\zeta-C(v',y))-(w+E(py-qg(y)+q\zeta-C(v',y))]^2$$
$$=\frac{U''}{2}\cdot E[(py-qg(y))+q\zeta-E(py)+E(qg(y))-E(q\zeta)]^2$$
$$=\frac{U''}{2}\cdot(E(py)^2-E^2(py)+E(qg(y))^2-E^2(qg(y))+E(q\zeta)^2-E^2(q\zeta)$$
$$-2E(pyqg(y))+2E(py)E(qg(y)+2E(pyq\zeta)-2E(py)E(q\zeta)$$
$$-2E(q^2\zeta g(y))+2E(q\ \zeta)E(qg(y))$$

Combining the terms gives

(b)
$$U(w+\pi)\approx EU[(w+E(py-q(g(y)-\zeta)-C(v',y))]$$
$$+\frac{U''}{2}\cdot(E(py)^2-E^2(py)+E(qg(y))^2-E^2(qg(y))+E(q\zeta)^2-E^2(q\zeta)$$
$$-2E(pyqg(y))+2E(py)E(qg(y)+2E(pyq\zeta)-2E(py)E(q\zeta)-$$
$$2E(q^2\zeta g(y))+2E(q\ \zeta)E(qg(y))$$
$$\approx EU[(w+E(\pi)]+\frac{U''}{2}\cdot[\mathrm{var}(\pi)]$$

where

$$\mathrm{var}(\pi)=y^2\ \mathrm{var}(p)+(g(y))^2\ \mathrm{var}(q)+(\zeta)^2\ \mathrm{var}(q)-$$
$$2g(y)\zeta\ \mathrm{var}(q)-2yg(y)\,\mathrm{cov}(p,q)+2y\zeta\ \mathrm{cov}(p,q)$$

Next, take a first order Taylor series expansion of $U(w+py-qg(y)-C(v',y)-R)$ with respect to R in the neighborhood of $[w+E(py-q(g(y)-\zeta)-C(v',y)-R]$. The expression is

(c)
$$U(w+\pi-R)\approx U(w+E(py-q(g(y)-\zeta)-C(v',y))-R)$$
$$+U'[(w+py-q(g(y)-\zeta)-C(v',y)-R)-(w+E(py-q(g(y)-\zeta)-C(v',y))-R)]$$

and from the definition of the risk premium R at $[w+E(py-q(g(y)-\zeta)-C(v',y)-R]$, $R=0$ and simplifying gives

(d) $$U(w+E(\pi)-R)\approx U(w+E(\pi))-U'\cdot R$$

By substituting the results from equations (b) and (d) into the definition of the risk premium, equation (2.8), I obtain

(e) $$U(w+E(\pi))+\frac{U''}{2}[\text{var}(\pi)]\approx U(w+E(\pi))-U'R$$

Given U'>0, equation (e) simplifies to

(f) $$R\approx -0.5(U''/U')\cdot[\text{var}(\pi)]$$

The result shows that in the neighborhood of the riskless case, the risk premium *R* is proportional to the variance of profit, $\text{var}(\pi)$ (Chavas 2004). The coefficient of proportionality is $[-0.5(\frac{U''}{U'})]$ thereby equation (f) is a local measure of the risk premium *R*. It follows that the risk premium *R* can be approximated in the "in the small" (Chavas 2004). Now following Chavas (2004), the Arrow-Pratt coefficient of absolute risk aversion is defined as $r\equiv -(\frac{U''}{U'})$. This allows the risk premium to be approximated as $R\approx (r/2)\cdot \text{var}(\pi)$. Since $\text{var}(\pi)>0$ for all nondegenerate random variables, it can be stated that the sign of the risk premium *R* is always the same sign as *r* (Chavas 2004). Further, from Jensen's inequality, given *U'>0*, and the definition of the risk premium, the result holds globally (Chavas 2004). Equation (f) then simplifies to

(2.8) $$R\approx \frac{r}{2}\cdot[\text{var}(\pi)]$$

where

$$\begin{aligned}\text{var}(\pi) = {} & y^2\,\text{var}(p)+(g(y))^2\,\text{var}(q)+(\zeta)^2\,\text{var}(q)-2g(y)\zeta\,\text{var}(q)\\ & -2yg(y)\,\text{cov}(p,q)+2y\zeta\,\text{cov}(p,q)\end{aligned}$$

APPENDIX B

CHAPTER THREE SO_2 SULFUR FINANCIAL INSTRUMENT (SFI) FUTURES

SFI 2010 futures contract specification sheet (ICE 2014).

ICE FUTURES U.S.

ICE Futures U.S.
Jul 31, 2013

Sulfur Financial Instrument Vintage 2010 Future

Contract Specifications

Description	Monthly physically delivered EPA SO2 Allowances under Title IV of the Clean Air Act ("U.S. EPA SO2 Emission Allowance").
Contract Symbol	SFI
Settlement Method	Physical delivery
Contract Size	25 U.S. EPA SO2 Emission Allowances
Currency	USD
Minimum Price Fluctuation	The price quotation convention shall be One cent ($0.01) per U.S. EPA SO2 Emission Allowance; minimum price fluctuation may vary by trade type. Please see Table in Resolution 1 to this Chapter 18.
Listing Cycle	1. Standard-cycle contract listings: a. Monthly contract sets for the current and coming calendar year; b. December contracts for up to forward 5 years 2. The Exchange may list any other calendar month contract set off the standard-cycle listing schedule through the last annual December contract set.
Last Trading Day	Three Business Days prior to the last Business Day of the delivery month
Deliverable Instruments	The U.S. EPA SO2 Emission Allowances acceptable for delivery are allowances having a vintage corresponding to the specified vintage and allowances having a vintage of any year prior to the specified vintage-year.
Registry	CAMD ATS

ICE FUTURES U.S.

Table B.1 ICE's SFI futures contracts listed (2004 - 2012)

Futures	Month	Year	Futures	Month	Year	Futures	Month	Year
SFI	March	2005	SFI	March	2006	SFI	January	2007
SFI	June	2005	SFI	April	2006	SFI	February	2007
SFI	September	2005	SFI	May	2006	SFI	March	2007
SFI	December	2005	SFI	June	2006	SFI	April	2007
			SFI	July	2006	SFI	May	2007
			SFI	August	2006	SFI	June	2007
			SFI	September	2006	SFI	July	2007
			SFI	October	2006	SFI	August	2007
			SFI	November	2006	SFI	September	2007
			SFI	December	2006	SFI	October	2007
						SFI	November	2007
						SFI	December	2007
SFI	January	2008	SFI	January	2009	SFI	January	2010
SFI	February	2008	SFI	February	2009	SFI	February	2010
SFI	March	2008	SFI	March	2009	SFI	March	2010
SFI	April	2008	SFI	April	2009	SFI	April	2010
SFI	May	2008	SFI	May	2009	SFI	May	2010
SFI	June	2008	SFI	June	2009	SFI	June	2010
SFI	July	2008	SFI	July	2009	SFI	July	2010
SFI	August	2008	SFI	August	2009	SFI	August	2010
SFI	September	2008	SFI	September	2009	SFI	September	2010
SFI	October	2008	SFI	October	2009	SFI	October	2010
SFI	November	2008	SFI	November	2009	SFI	November	2010
SFI	December	2008	SFI	December	2009	SFI	December	2010
SFI	January	2011	SFI	January	2012			
SFI	February	2011	SFI	February	2012			
SFI	March	2011	SFI	March	2012			
SFI	April	2011						
SFI	May	2011						
SFI	June	2011						
SFI	July	2011						
SFI	August	2011						
SFI	September	2011						
SFI	October	2011						
SFI	November	2011						
SFI	December	2011						

Source: compilation from Bloomberg (2014).

APPENDIX C

CHAPTER FOUR CO_2 EUROPEAN UNION ALLOWANCE FUTURES

EUA Phase 2 Daily Futures

Contract Specifications

Description	The EUA Phase 2 Daily Futures Contract is a deliverable contract where each Clearing Member with a position open at cessation of trading for a contract month is obliged to make or take delivery of Phase 2 EUAs to or from National Registries in accordance with the ICE Futures Europe Regulations.
Units of Trading	One lot of 1000 Emission Allowances. Each Emission Allowance being an entitlement to emit one tonne of carbon dioxide equivalent gas during the relevant period
Relevant Period	Phase 2 compliance period
Commodity Code	ECS
Minimum Trading Size	1 lot.
Quotation	Euro (€) and Euro cent (c) per metric tonne.
Tick Size	€0.01 per tonne (i.e. €10.00 per lot).
Minimum Price Flux	€0.01
Maximum Price Flux	no limit
Contract Listings	The Contract is a Daily Contract. Only one Daily Contract is listed at any one time
Trading System	Trading will occur on the ICE Futures Europe electronic trading platform known as the ICE Platform accessible via WebICE or through a conformed Independent Software Vendor
Trading Hours	07:00 hours to 17:00 hours UK Local Time.

Contract Specifications

Settlement Price	Trade weighted average during the daily closing period (16:50:00 – 16:59:59 UK Local Time) with Quoted Settlement Prices if low liquidity. The settlement price will become the Exchange Delivery Settlement Price (EDSP)
VAT & Taxes	s UK's HM Revenue and Customs has confirmed that the trading of the ICE EUA Daily Futures Contract on the Exchange between the Member and ICE Clear Europe Limited has been granted interim approval to be zero-rated for VAT purposes under the terms of the Terminal Markets Order.
Delivery Methods	The Contracts are physically deliverable by the transfer of Emission Allowances from an acceptable Trading Account of the Selling Clearing Member at the Union Registry to the specified Trading Account of ICE Clear Europe at the Union Registry and from the Trading Account of ICE Clear Europe at the Union Registry to an acceptable Trading Account of the Buying Clearing Member at the Union Registry. Delivery is between Clearing Members and ICE Clear Europe during a Delivery Period. The Delivery Period is the period beginning at 17.00 hours local London time on the Contract Date and ending at 15.00 hours local London time on the second Business Day following the relevant Contract Date.
Clearing	ICE Clear Europe will act as central counterparty to all trades.
Contract Security	ICE Clear Europe guarantees the financial performance of the ICE Futures Europe contracts entered into in the name of its Clearing Members, in accordance with the Clearing Rules
Other Information	Block Trades are available for this contract, with a minimum size of 50 lots. EFPs/EFSs are also available

Table C.1 Phase II and III EUA Futures Contracts Listed

EUA Futures Phase II and III (1-3 months)

EUA	Dec	2008
EUA	Mar	2009
EUA	June	2009
EUA	Sept	2009
EUA	Dec	2009
EUA	Mar	2010
EUA	June	2010
EUA	Sept	2010
EUA	Dec	2010
EUA	Mar	2011
EUA	May	2011
EUA	June	2011
EUA	Jul	2011
EUA	Aug	2011
EUA	Sep	2011
EUA	Oct	2011
EUA	Nov	2011
EUA	Dec	2011
EUA	Jan	2012
EUA	Feb	2012
EUA	Mar	2012
EUA	April	2012
EUA	May	2012
EUA	June	2012
EUA	Jul	2012
EUA	Aug	2012
EUA	Sep	2012
EUA	Oct	2012
EUA	Nov	2012
EUA	Dec	2012
EUA	Jan	2013
EUA	Feb	2013
EUA	Mar	2013
EUA	April	2013
EUA	May	2013
EUA	June	2013
EUA	Jul	2013
EUA	Aug	2013
EUA	Sep	2013
EUA	Oct	2013
EUA	Nov	2013
EUA	Dec	2013

EUA Futures Phase II and III (1-12 months)

EUA	Dec	2008
EUA	Mar	2009
EUA	June	2009
EUA	Sep	2009
EUA	Dec	2009
EUA	Mar	2010
EUA	June	2010
EUA	Sep	2010
EUA	Dec	2010
EUA	Mar	2011
EUA	June	2011
EUA	Sep	2011
EUA	Dec	2011
EUA	Mar	2012
EUA	June	2012
EUA	Sep	2012
EUA	Dec	2012
EUA	Mar	2013
EUA	June	2013
EUA	Sep	2013
EUA	Dec	2013

APPENDIX D

DERIVATIONS OF CHAPTER SIX EQUATIONS

The appendix is numbered such that a section or equation corresponds to the text reference (D.#). Any equation written as (#) corresponds to its place in the main body of text. In the appendix, derivations (letters) are used to denote equations used in solving for the appendix value.

(D.1) The firm's maximization problem is expressed in terms of *H* and *y* in (6.3).

$$Max_{H,y,z}\{EU(w+py-q(z-\zeta)+(\psi-F)H)-Min_{x}\{v'x:\ y=f(x)\}:\ z=g(y)\}$$

$$Max_{H,y,z}\{EU(w+py-q(z-\zeta)+(\psi-F)H-C(v',y):\ z=g(y)\}$$

$$Max_{H,y}\{EU(w+py+q\zeta+(\psi-F)H-C(v',y)+Max_{z}\{-qz:\ z=g(y)\}\}$$

(6.4) $$Max_{H,y}\{EU(w+py-q(g(y)-\zeta)+(\psi-F)H-C(v',y))\}$$

(D.2) Derivation of (6.7). Using Feder 1977, Lemma 4. For any x_i, x_j such that

$\iota_i \neq 0,\ \iota_j \neq 0,\ \phi_i \neq 0,\ \phi_j \neq 0$ it holds that $A_i/\iota_i = A_j/\iota_j$ and $A/\phi_i = A_j/\phi_j$.

By setting $A_i = (p-qg'-C')$ and $A_j = (\psi - F)$, and because once g' is given it can be treated as a constant, we set ϕ_i = -g' and $\phi_j = 1$. Now by applying Feder Lemma 4, $A_i/\phi_i = A_j/\phi_j$ such that $A_i/-g' = A_j/1$ yields

(6.7) $$A_i = -g'*(A_j)$$

(D.3) The Hessian, denoted as ∇^2, from (6.5) and (6.6) using (6.7) is

$$\nabla^2 = \begin{bmatrix} \frac{\partial^2 U}{\partial y^2} & \frac{\partial^2 U}{\partial H \partial y} \\ \frac{\partial^2 U}{\partial y \partial H} & \frac{\partial^2 U}{\partial H^2} \end{bmatrix},$$

and by simplification and the chain rule

$$\frac{\partial^2 U}{\partial y^2}: E[\left(\frac{\partial U'}{\partial U}\right)\cdot\left(\frac{\partial U}{\partial y}\right)\cdot(p-qg'-C')+U'\cdot\partial(p-qg'-C')/\partial y]$$
$$= E[U''\cdot(p-qg'-C')^2 + U'\cdot(-qg''-C'')]$$
$$= E[U''\cdot(A_i)^2 - U'\cdot(qg''+C'')]$$
$$= E(U''A_i^2) - g''E(U'q) - c''E(U')$$

and

$$\frac{\partial^2 U}{\partial H\partial y}: E[\left(\frac{\partial U'}{\partial U}\right)\cdot\left(\frac{\partial U}{\partial H}\right)\cdot(p-qg'-C')+U'\cdot\partial(p-qg'-C')/\partial H]$$
$$= E[U''\cdot(q-F)(p-qg'-C') \quad + U'\cdot 0]$$
$$= -E[U''\cdot(A_i)^2/g']$$

where $\frac{\partial^2 U}{\partial H\partial y} = \frac{\partial^2 U}{\partial y\partial H}$

Next,

$$\frac{\partial^2 U}{\partial H^2}: E[\left(\frac{\partial U'}{\partial U}\right)\cdot\left(\frac{\partial U}{\partial H}\right)\cdot(q-F)+U'\cdot\partial(q-F)/\partial H]$$
$$= E[U''\cdot(q-F)^2 + U'\cdot 0]$$
$$= E[U''\cdot(A_i)^2/(g')^2]$$

(D.4) The second order condition for (6.8) using the Hessian is

$$D = \left|\nabla^2\right| = \left(\frac{\partial^2 U}{\partial y^2}\right)\left(\frac{\partial^2 U}{\partial H^2}\right) - \left(\frac{\partial^2 U}{\partial H\partial y}\right)\left(\frac{\partial^2 U}{\partial y\partial H}\right)$$
$$= \left(E[U''\cdot(A_i)^2 - U'\cdot(qg''+C'')]\right)\cdot\left(E[U''\cdot(A_i)^2/(g')^2]\right) - \left(-E[U''\cdot(A_i)^2/g']\right)^2$$
$$= [-g''E(U'q) - c''E(U')][E(U''\cdot A_i^2)/(g')^2]$$
$$= -g''E(U'q)\cdot E[(U''\cdot A_i^2)/(g')^2] - c''E(U')\cdot[E(U''\cdot A_i^2)/(g')^2]$$

(D.5) solving for emissions production in (6.9). First from Feder Lemma 4, used in eq. (6.7), eq. (6.6) becomes (6.b), $E[U'\cdot(g'F - g'\psi)] = 0$. Next set (6.6b) equal to (6.5)

$$E[U'\cdot(p-qg'-C')] = E[U'\cdot(g'F - g'q)] = 0$$

(a) $$E[U'p] - E[U'q]g' - E[U']C' = E[U']Fg' - E[U'\psi]g'$$

Then by using expectations of p, q, and ψ, output prices are

(b)
$$E[U'p] = Cov(U', p) + E[U']E[p]$$
$$E[U'p] = Cov(U', p) + E[U']E[\mu] + E[U']E[\sigma e]]$$
$$E[U'p] = Cov(U', p) + E[U']\mu$$

(c)
$$E[U'q] = Cov(U', q) + E[U']E[q]$$
$$E[U'q] = Cov(U', q) + E[U']E[\eta] + E[U']E[\lambda\varepsilon]$$
$$E[U'q] = Cov(U', q) + E[U']\eta$$

(d)
$$E[U'\psi] = Cov(U', \psi) + E[U']E[\psi]$$
$$E[U'\psi] = Cov(U', \psi) + E[U']E[\eta] + E[U']E[\lambda\varepsilon] + E[U']E[\varsigma\theta],$$
$$E[U'\psi] = Cov(U', \psi) + E[U']\eta$$

respectively, where the permit spot and futures covariance terms can be expressed as

(e)
$$Cov(U', q) = E[U'q] - E[U']E[q]$$
$$= E[U'\cdot(\eta + \lambda\varepsilon)] - E[U']E[\eta + \lambda\varepsilon]$$
$$Cov(U', q) = E[U'\lambda\varepsilon]$$

(f)
$$Cov(U', \psi) = E[U'\psi] - E[U']E[\psi]$$
$$= E[U'\cdot(\eta + \lambda\varepsilon + \varsigma\theta)] - E[U']E[\eta + \lambda\varepsilon + \varsigma\theta]$$

Here, based on the spot and futures traits in exchange leading to a zero basis, $\varsigma\theta$ becomes zero; this is a rational assumption. If it did not hold, the firm could find profitable arbitrage trades. Part (f) then simplifies to

$$Cov(U', \psi) = E[U'\lambda\varepsilon]$$

Now by replacing the terms in (a) with (b)-(f), (4) can be stated as

$$Cov(U', p) + E[U']\mu - E[U']\eta g' - g'E[U'\lambda\varepsilon] - E[U']C = E[U']Fg' - E[U']\eta g' - g'E[U'\lambda\varepsilon]],$$

which simplifies to

(6.9)
$$\frac{\partial EU}{\partial y}: \quad \mu - Fg' = C' - \frac{Cov(U', p)}{E[U']}$$

(D.6) Forming the profit variance of (6.10) and risk premium of (6.11)

The firm's risk premium is found by combining two Taylor series expansions. A second order Taylor series expansion of $U(w + py - q(g(y) - \zeta) + (\psi - F)H - C(v, y))$ in the neighborhood of $[w + E(py - q(g(y) - \zeta) + (\psi - F)H - C(v, y))]$ can be expressed as

(a)

$$
\begin{aligned}
U(w+\pi) \approx\ & EU[(w + E(py - q(g(y) - \zeta) + (\psi - F)H - C(v, y)) \\
& + U' \cdot E[(w + py - q(g(y) - \zeta) + (\psi - F)H - C(v, y)) - (w + E(py - q(g(y) - \zeta) + (\psi - F)H - C(v, y))] \\
& + \frac{U''}{2} \cdot E[(w + py - q(g(y) - \zeta) + (\psi - F)H - C(v, y)) - (w + E(py - q(g(y) - \zeta) + (\psi - F)H - C(v, y))]^2
\end{aligned}
$$

where $U' = \partial U / \partial w$ is the first derivative of the utility function, and $U'' = \partial^2 U / \partial w^2$ is the second derivative, each evaluated at $(w + E(\pi))$. After taking the expectation

$$
\begin{aligned}
\approx & EU[(w + E(py - q(g(y) - \xi) + (\psi - F)H - C(v, y))] \\
& U' \cdot [E(py) - E(qg(y)) + E(q\xi) + E(\psi h) - E(FH) - E(C(v, y)) - E(py) \\
& + E(qg(y)) - E(q\xi) - E(qh) + E(FH) + E(C(v, y))] \\
& + \frac{U''}{2} \cdot [\ (py - qg(y) + q\xi + \psi H - E(py) + E(qg(y)) - E(q\xi) - E(\psi H))^2]
\end{aligned}
$$

$$
\begin{aligned}
\approx & EU[(w + E(py - q(g(y) - \xi) + (q - F)H - C(v, y))] \\
& + \frac{U''}{2} \cdot [\ E(py)^2 - E^2(py) + E(qg(y))^2 - E^2(qg(y)) + E(q\xi)^2 - E^2(q\xi) \\
& + E(\psi H)^2 - E^2(\psi H) - 2E(pyqg(y)) + 2E(py)E(qg(y)) + 2E(pyq\xi) \\
& - 2E(py)E(q\xi)) + 2E(py\psi H)) - 2E(py)E(\psi H) - 2E(q^2 g(y)\xi) \\
& + 2E(q\xi)E(qg(y)) - 2E(qg(y)\psi H) + 2E(qg(y)E(\psi H) + 2E(q\xi\psi H) \\
& - 2E(q\xi)E(\psi H)]
\end{aligned}
$$

$$
\approx EU[(w + E(\pi)] + \frac{U''}{2} \cdot \operatorname{var}(\pi)
$$

where the variance of profits is

$$\text{var}(\pi) = y^2 \text{ var}(p) - g(y)^2 \text{ var}(q) + \zeta^2 \text{ var}(q) + H^2 \text{ var}(\psi)$$
(6.10) $$-2yg(y) \text{ cov}(p,q) + 2y\zeta \text{ cov}(p,q) + 2yH \text{ cov}(p,\psi)$$
$$-2g(y)\zeta \text{ var}(q) - 2g(y)H \text{ cov}(q,\psi) + 2\zeta H \text{ cov}(q,\psi)$$

(b) $$U(w+\pi) \approx EU[(w+E(\pi)] + \frac{U''}{2} \cdot [\text{var}(\pi)]$$

Next, take a first order Taylor series expansion of

$U(w + py - q(g(y) - \bar{z}) + (\psi - F)H - C(v', y) - R)$ with respect to *R* in the neighborhood

of $[w + E(py - q(g(y) - \bar{z}) + (\psi - F)H - C(v', y)) - R]$. The expression is

(c) $$U(w+\pi-R) \approx U(w+E(\pi)-R) + U'[(w+\pi-R)-(w+E(\pi)-R)]$$

and from the definition of the risk premium *R* at $[w + E(\pi) - R]$, *R=0*. Simplifying gives

(d) $$U(w+E(\pi)-R) \approx U(w+E(\pi)) - U' \cdot R$$

By substituting the results from equations (c) and (d) into the definition of the risk premium, equation (11), we obtain

(e) $$U(w+E(\pi)) + \frac{U''}{2}[\text{var}(\pi)] \approx U(w+E(\pi)) - U'R$$

Given U'>0, equation (e) simplifies to

(f) $$R \approx -0.5(U''/U') \cdot [\text{var}(\pi)]$$

The result shows that in the neighborhood of the riskless case, the risk premium *R* is proportional to the variance of profit, $\text{var}(\pi)$ (Chavas 2004). The coefficient of proportionality is $[-0.5(\frac{U''}{U'})]$ thereby equation (f) is a local measure of the risk premium *R*. It follows that the risk premium *R* can be approximated in the "in the small" (Chavas 2004). Now following Chavas (2004), the Arrow-Pratt coefficient of absolute risk aversion is defined as $r \equiv -(\frac{U''}{U'})$. This allows the risk premium to be approximated as

$R \approx (r/2)\cdot \text{var}(\pi)$. Since $\text{var}(\pi) > 0$ for all nondegenerate random variables, it can be stated that the sign of the risk premium *R* is always the same sign as *r* (Chavas 2004). Further, from Jensen's inequality, given *U'>0*, and the definition of the risk premium, the result holds globally (Chavas 2004). Equation (f) then simplifies to

(e) $R \approx \frac{r}{2}\cdot[\text{var}(\pi)]$

which is the risk premium used in eq. (6.11)

(D.7) Expressing the hedge ratio correlation coefficient of permit futures and electricity prices as expectations in equation (6.15). The $\text{cov}(p,\psi)$ is

$$\begin{aligned}\text{cov}(p,\psi) &= E(p\psi) - E(p)E(\psi)\\ &= E[(\mu+\sigma e)(\eta+\lambda\varepsilon)] - E(\mu+\sigma e)E(\eta+\lambda\varepsilon)\\ &= E(\mu\eta+\mu\lambda\varepsilon+\eta\sigma e+\sigma e\lambda\varepsilon) - E(\mu)E(\eta)\\ &= E(\sigma e\lambda\varepsilon)\end{aligned}$$

The variance of electricity price, $E(p) = \mu + \sigma e$, is $\text{var}(p) = E[(\sigma e)^2]$; and the variance of permit futures price is $\text{var}(\psi) = E[(\lambda\varepsilon)^2]$. After substitution and solving for ρ we have

(6.15) $\rho = \left[\frac{E(\sigma e\lambda\varepsilon)}{E[(\lambda\varepsilon)^2]}\right] / \left[\sqrt{\frac{E[(\sigma e)^2]}{E[(\lambda\varepsilon)^2]}}\right]$

APPENDIX E

DERIVATIONS OF CHAPTER SEVEN EQUATIONS

(E.1) Proof of $\beta_2=\beta_3$ being a necessary condition for semi-strong form futures market efficiency.

The null hypothesis $\beta_2=\beta_3$, is that the weight $(\beta_2 - \beta_3)$ on spot prices and opportunity costs $\beta_2(1+r_t)q_t$ is zero in an implied composite forecast with futures. It is shown below that the null hypothesis $\beta_2=\beta_3$ is also a test that the futures encompass all useful pricing information contained within the spot price and opportunity costs, $\beta_2(1+r_t)q_t$ which is a necessary condition for semi-strong form futures efficiency. To establish this necessary condition within equation (7.6), a proof of the parallels between the null hypothesis $\beta_2=\beta_3$ and the encompassing principle null hypothesis of $\lambda_1 = 0$, is shown.

The forecast encompassing principle was developed by Harvey, Leybourne and Newbold (1997, 1998) and Harvey and Newbold (2000) to test if one forecast contains more or less information relative to another. Sanders and Manfredo (2005) extended the encompassing principle to futures market evaluation and provided a proof that it can be used as a necessary condition for semi-strong form efficiency[81].

In construction for use in eq. (7.6), I use eq. (7.3) and (7.5) as two competing permit price forecasts. For this description consider the error term notation as applying only to this appendix; this is for consistency in exposition with that of Harvey, Leybourne, and Newbold (1997, 1998). Also the time subscript for different monthly horizons (i) is dropped. The futures forecast is

[81] See Sanders and Manfredo (2005 pg. 2-3) for the detailed example and discussion of the MSE vs. the encompassing principle.

(a) $A_T = \alpha_1 + \alpha_2 F_t^T + e_{1t}$,

and the benchmark forecast is

(b) $A_T = \alpha_3 + \alpha_4 (1 + r_{t,T}) s_t + e_{2t}$,

where model (a) represents futures ability to accurately predict later prices with an error of e_{1t} and model (b) represents the benchmark forecast's ability to accurately predict later prices with an error of e_{2t}.

Forecast encompassing can be tested with the following regression-based model:

(c) $e_{1t} = \alpha + \lambda_1 (e_{1t} - e_{2t}) + \varepsilon_{t.}$

where, e_{1t} is the forecast error series of the preferred forecast (futures), and e_{2t} is the forecast error series of the benchmark forecast. The null hypothesis is, $\lambda_1 = 0$, which is a test that the covariance between e_{1t} and (e_{1t} - e_{2t}) is zero[82]. A failure to reject the null hypothesis implies a composite forecast cannot be constructed from the two series that would result in a smaller expected squared error than using the preferred forecast by itself. That is, the preferred forecast "encompasses" the competing forecast's predictive information (Harvey, Leybourne, and Newbold 1998, Sanders and Manfredo 2005). If the futures encompass the alternative forecast's information, it is conditionally efficient with respect to the two forecasts - a necessary condition for semi strong form market efficiency (Sanders and Manfredo 2005).

By returning to our test equation

(7.6) $A_T = \beta_1 + \beta_2 (1 + r_t) q_t + \beta_3 [F_t^T - (1 + r_t) q_t] + e_{3t}$

[82] For an additional proof see Granger and Newbold (1986 pg. 267) who establish the encompassing principle in the context of the correlation between forecasts.

it will be shown that $\beta_2=\beta_3$ is parallel to testing the null $\lambda_1 = 0$ in equation (c). First by multiplying through β_3 and moving the futures price to the left hand side (7.6) becomes

(d) $$A_T - \beta_3(F_t^T) = \beta_1 + \beta_2(1+r_t)q_t - \beta_3(1+r_t)q_t + e_{3t}.$$

Next by adding and subtracting A_T to the right-hand-side and rearranging yields

(e) $$A_T - \beta_3(F_t^T) = \beta_1 + [A_T - \beta_3(1+r_t)] - [A_T - \beta_2(1+r_t)q_t] + e_{3t}$$

From (e) the preferred forecast properties can be tested by

(g) $$A_T - \beta_3(F_t^T) = \beta_1 + \lambda_2\big([A_T - \beta_3(1+r_t)] - [A_T - \beta_2(1+r_t)q_t]\big) + e_{3t}$$

which allows for testing the null hypothesis, $\lambda_2 = 0$ whose properties also reflect the null hypothesis $\beta_2=\beta_3$. A failure to reject the null hypothesis $\lambda_2 = 0$ implies a composite forecast cannot be constructed from the two series that would result in a smaller expected squared error than using the preferred (futures) forecast by itself. In eq. (e) the null hypothesis, $\lambda_2 = 0$ matches that of the encompassing principle, $\lambda_1 = 0$ described in eq. (c). Thus, within our test equation (7.6) a failure to reject the null hypothesis $\beta_2=\beta_3$ suggests the futures forecast "encompasses" or is "conditionally efficient" with respect to the benchmark forecast (Harvey, Leybourne, and Newbold, 1998).

There is an important difference between Harvey Leybourne, and Newbold's encompassing test in (c) and that implied by eq. (7.6) used here. Namely, Harvey, Leybourne, and Newbold's encompassing method imposes a unitary weight on the preferred forecast, $\beta_3=1$ in (c). They assume that the preferred forecast is rational and receives a weight (scaling) of 1 under the null hypothesis. In applications, this may or may not be the case. Here eq. (7.6) only requires that the coefficient of the preferred forecast equal that of the competing forecast $\beta_2=\beta_3$ a more flexible form of evaluation. If the restriction of unity is binding, it may lead to a more frequent rejection of the null hypothesis using the encompassing test than when using the procedure developed here (emphasizing the procedure used here is based on the forecasting test of Vuchelen and Gutierrez).

(E.2) *Missing observations in futures price series*

Missing observations were filled in by creating an implied value based on the other futures prices available at the point in time of the missing observation. The procedure followed is described below. For exposition it considers that a two month out futures contract price F_t^{t2} is missing. To create an implied value the one month out futures F_t^{t1} and three month out futures F_t^{t3} are used. First values for *x* and *y* are found as

(a) $$x = (F_t^{t1} - s_t)/(t1 - t)$$

and

(b) $$y = (F_t^{t3} - F_t^{t1})/(t3 - t1)$$

where s_t is the spot price and *t#* represents the days from *t* until the respective futures contract matures. For example *t3* would be the number of days from *t* until the three month out futures matured. Because of various month lengthens, holidays, and the exchange trading dates - actual days for each point in time were calculated. The values of *x* and *y* were then used to solve

(c) $$F_t^{t2} = F_t^{t1} + [(x * \left(1 - \frac{(t2 - t1)}{(t3 - t1)}\right)) + (y * \left(1 - \frac{(t3 - t2)}{(t3 - t1)}\right))] * (t2 - t1)],$$

creating an implied value for the missing observation.