# INTERTEMPORAL PRICING OF SULFUR DIOXIDE ALLOWANCES

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## ABSTRACT

The Clean Air Act Amendments of 1990 initiated the first large-scale use of the tradable permit approach to pollution control. The theoretical case for this approach rests on the assumption of an efficient market for emission rights. This paper presents the inter-temporal pattern of allowance prices that should be observed in the market for sulfur dioxide allowances in world of certainty with no transaction costs, and demonstrates that this pattern is roughly consistent with what is observed. Where there are deviations, these deviations can be explained using the theory that is applied to other well established, well functioning markets. The empirical analysis in this paper suggests that the forward market for emission rights has become reasonably efficient.

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## 1. Introduction

Title IV of the 1990 Clean Air Act Amendments (CAAA)[1] established the first large-scale, long-term environmental program to rely on tradable emissions permits to control pollution. This program was designed to cut acid rain by reducing sulfur dioxide ($SO_2$) emissions from electric generating plants to about half their 1980 level, beginning in 1995. Acid rain (or, more properly, acid deposition) occurs when $SO_2$ and nitrogen oxides react in the atmosphere to form sulfuric and nitric acids, respectively.[2] These acids then fall to earth, sometimes hundreds of miles from their source, in either wet or dry form. The restrictions on $SO_2$ emissions are applied in two phases. Phase I covers the 263 dirtiest large generating units in the country and requires them, in the aggregate, to reduce their emissions substantially, to about 5.7 million tons per year, during the period 1995 - 1999.[3] Phase II, which begins in 2000, tightens the emissions cap further and extends it to virtually all electric generating units in the continental U.S.

Title IV embraces emissions trading with remarkably few restrictions. The law created *de facto* property rights for emissions, called "allowances" in this program, that can be freely traded and it gives electric utilities complete flexibility in determining how they will comply with their obligations under the law. To allow utilities to take advantage of inter-temporal cost savings, Title IV allows utilities to bank unused allowances for use in future years. Allowances can be traded nationally, though the environmental problem being addressed is regional.[4] No review or prior approval of trades is necessary. The purchase and holding of allowances is not restricted to the utilities for whom these permits would become a necessary input for the generation of electricity. All sources receiving allowance allocations as well as third parties, such as brokers and individuals, are free to buy or sell allowances with any other party. Neither the frequency nor the mechanisms for trading allowances are

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[1] The 1990 CAAA is Public Law 101-549.

[2] The Acid Rain Program also aims to reduce nitrogen oxide ($NO_X$) emissions by fifty percent from 1980 levels. The $NO_X$ aspect permits only limited intra-utility trading among sources.

[3] In fact, an additional 182 generating units that were not otherwise due to become "affected sources" until Phase II became affected in Phase I through special (substitution unit or compensating unit) provisions of a compliance plan for one or more of the original 263 Phase I units. See EPA 1996 for statistics and Joskow and Schmalensee 1998 for summaries of these provisions.

[4] The concern that regional patterns of emissions reductions would result in "hot spots" have not been realized (EPA 1996).

limited.    Finally, Section 416(d)(2) of the 1990 CAAA withheld a small fraction (2.8%) of the allowances to be issued to utilities and mandated that they be sold at an annual revenue neutral Environmental Protection Agency (EPA) administered auction.  The vast majority of allowance trading has involved bilateral private trades between utilities that own electric generators or between those utilities and third parties, although some allowances have been traded through the annual set of auctions that the EPA is required to hold.[5]

Economists have long argued that, in theory, the tradable permit approach to pollution control should involve significantly lower costs than the traditional command-and-control approach of specifying source-specific standards.[6] This argument, of course, rests on the assumption that the market for permits is reasonably efficient.  The limited experience with emissions trading prior to 1990 was not particularly encouraging to this end (Hahn 1989, Hahn and Hester 1989), and there was considerable doubt whether this feature of Title IV would meet with any greater success than had earlier experiments with emissions trading.[7]

Joskow, Schmalensee, and Bailey (1998), denoted herein as JSB, rely on "spot" allowance prices reported by private market making organizations and clearing prices in the "spot" EPA auctions as well as bidding behavior in the annual EPA auctions to demonstrate that the market for $SO_2$ allowances had become reasonably efficient by mid-1994, a full year and a half before utilities had to relinquish to the EPA allowances to cover their emissions in the first year of the program.  The close alignment of prices quoted from several independent sources in conjunction with the flattening of the bidders' offer curves in the annual EPA auctions strongly suggest the emergence of a competitive market for $SO_2$ allowances.

This paper provides additional evidence toward the proposition that the $SO_2$ allowance market has become reasonably efficient. Because $SO_2$ abatement strategies involve investment and contracting

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[5] Joskow, Schmalensee, and Bailey 1998.

[6] On the economics of the tradable permit approach, see Tietenberg 1985.

[7] Smaller scale programs employing tradable permits to phase-out leaded gasoline and CFCs have been met with somewhat more success  (NERA 1994).

decisions that affect emissions for many years, a forward market for allowances should be expected to emerge if utilities take advantage of opportunities for inter-temporal cost savings made possible by the banking provisions of Title IV. Moreover, because Title IV allows unused allowances to be carried forward for use in future years, a predictable term structure should be observed between current and future allowances. In fact, an active inter-temporal market for $SO_2$ allowances has emerged. In this paper, the forward market for $SO_2$ allowances is examined and found to be reasonably efficient, consistent with the hypothesis put forth by JSB.[8]

The organization of the remainder of the paper is as follows. The next section outlines Title IV of the 1990 CAAA, the associated allowance trading system, and the role of forward market transactions. Section 3 examines, in theory, the intertemporal pattern of allowance prices expected to be observed in the $SO_2$ allowance market. Section 4 considers data from the forward market for allowances and the term structure of allowance prices. Section 5 presents conclusions.

## 2. Title IV and Inter-temporal Allowance Trading

The basic approach to emissions control embodied in Title IV is simple: An aggregate annual cap on national $SO_2$ emissions defines the number of emission allowances available for allocation to electricity generating units each year. An emissions allowance is the right to emit one ton of $SO_2$ into the atmosphere. To emit $SO_2$ legally during a given year, an affected unit (one subject to Title IV's $SO_2$ constraint) must have enough allowances that are good for use in that year to cover all its $SO_2$ emissions. Title IV also requires each affected unit to have a continuous emissions monitoring system on each exhaust stack to measure actual $SO_2$ emissions and to report those emissions to the EPA. At the end of each year, each source must have deposited enough allowances in an account maintained for it by the EPA to cover all of its recorded emissions or be subject to significant financial (and legal) penalties.

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[8]Options and other derivative instruments have also emerged in the $SO_2$ allowance market in recent years. In addition, an active swap market has emerged. A utility which needs allowances today but expects to have excess allowances in 2000 will often find it tax-efficient to "swap" allowances with another entity rather than buy allowances today and sell allowances in, say, 2000. See Bartels 1997.

Title IV specifies the initial allocation of $SO_2$ allowances. Allowances are given to existing electric generating units and those under construction according to fairly complicated rules that are discussed in detail by Joskow and Schmalensee (1998). For purposes of this paper it suffices to note that essentially all of the allowances available to cover $SO_2$ emissions were allocated "free" to incumbent sources.

Each allowance specifies a particular year, its "vintage", in which it is first available to be used to cover $SO_2$ emissions. An allowance can also be "banked" and used in any future year. Thus, for instance, a "1996 vintage" allowance can be used to cover emissions in 1996 or held for use in any later year, but it cannot be used to cover 1995 emissions. Most importantly, all allowances are fully tradable. That is, a source that has been allocated allowances is free to sell them to any other source, including to a third party such as brokers and individuals. Moreover, an affected source can buy allowances to cover its present emissions or its future emissions from any type of trading partner. There are no limitations on how often parties can trade allowances or on the trading mechanisms that buyers and sellers may use to trade them. Finally, Title IV created a set of small revenue-neutral allowance auctions in order to "jump-start" the market. The auctions, which are administered by the EPA, occur only once a year and cover only two or three vintages at a time. Each year, roughly 2.8% of the allowances that have been allocated to utilities are held back and auctioned in annual "spot" and "seven-year advance" auctions. In addition, in 1994 through 1997 a "six-year advance" auction was also held because allowances available in the "Direct Sales Reserve" provision of the law were not sold. Allowances sold in the seven (six) year advance auction are first usable seven (six) years after the auction. For example, in the 1993 seven-year advance auction, vintage 2000 allowances were sold; in the 1994 seven-year advance auction, vintage 2001 allowances were sold, and so on. The revenues from all these auctions are returned to the sources in proportion to their share of the allowances that were held back for the auctions.

At the very least, a forward market for $SO_2$ allowances should be expected to develop in order for participants to price the six and seven year advance auction allowances sold by the EPA since auction participants can purchase the spot allowances sold in the EPA auction and carry them forward for six or seven years or alternatively simply purchase the six or seven year advance allowances. Moreover though, a robust private market for forward allowances should be expected to develop since compliance decisions by electric utilities are often long term investment decisions frequently requiring

streams of allowances involving many consecutive vintages. In addition, utilities with excess vintage 1995 allowances to sell, for example, typically also have excess allowances of several adjacent vintages to sell. Similarly, utilities needing to purchase vintage 2000 allowances, for example, typically also need to purchase several adjacent vintages as well. Moreover, utilities responding to current and future allowance needs require the flexibility to buy or sell allowances at any time not just in the year the allowances are needed for compliance purposes.

Table 1 reports information on the number of spot[9] and forward allowances that appear to have been traded in arms-length transactions through December 1997. Following JSB, Table 1 is constructed using data from the EPA's Allowance Tracking System in order to create a conservative lower bound estimate of the volume of arms-length trading during various time periods between 1992, when the first trades took place, and December 31 1997. Arms length transactions include both private market transactions as well as EPA auction transactions. The details of how estimates of private market trades have been constructed are available in JSB. For a variety of reasons discussed in JSB, the recorded data in the EPA's allowance tracking system may underestimate actual commercial transactions to some extent.

Table 1 demonstrates that there has in fact been considerable arms-length trading in forward (non-spot) allowances. By the end of December 1997, approximately 9.2 million non-spot vintage allowances had been traded in arms length transactions, slightly less than half of the total number of allowances of all vintages, 19.5 million, transacted in the same period. It is also evident from Table 1 that there was little forward vintage allowance transactions prior to the start of 1995. About 8.8

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[9] A 1995 spot allowances is a 1995 allowance. Because allowances can be banked, a 1996 spot allowance is a 1995 or a 1996 allowance and a 1997 spot allowance is a 1995, 1996 or 1997 allowance.

**Table 1**

**Allowances Sold in EPA Auction and Private Market[*], By Vintage**

|  | Vintage "Spot" [**] | Vintage (Spot+1)-1999 | Vintage 2000-2005 | Vintage 2006-20025 | All Vintages |
|---|---|---|---|---|---|
| Through 1993 | 250,430 | 100,060 | 151,003 | 51,106 | 552,599 |
| Jan. 1994 – Dec. 1994 | 310,170 | 332,132 | 509,931 | 228,006 | 1,380,239 |
| Jan. 1995 – Dec. 1995 | 1,759,960 | 942,978 | 1,108,522 | 883,468 | 4,694,928 |
| Jan. 1996 – Dec. 1996 | 2,933,933 | 388,926 | 1,259,863 | 690,327 | 5,273,049 |
| Jan. 1997 – Dec. 1997 | 5,103,357 | 452,477 | 1,463,931 | 637,764 | 7,657,529 |
| **Total** | **10,357,850** | **2,216,573** | **4,493,250** | **2,490,671** | **19,558,344** |

of the 9.2 million forward allowances that were traded up through the end of December 1997 were traded after December 1993 and about 7.8 of the 9.2 million forward allowances that were traded were traded after December 1994. In addition, Table 1 indicates that a larger number of forward vintage allowances denominated in the years 2000-2005 were traded compared to forward vintage allowances denominated in remaining Phase 1 years and compared to vintage year allowances denominated in the years 2006-2025. There are two reasonable explanations for why a larger number of forward allowances denominated in vintages between 2000 and 2005 were traded compared to other forward

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[*] The number of allowances sold in the private market includes inter-utility trades, trades between utilities and third parties, and trades between two non-utility parties. This number excludes intra-utility trades (including intra-holding company trades), reallocations, and options to trade which have not been exercised.

vintage allowances.  First, the six and seven year advance auction allowances that have been sold in the annual EPA auctions all fall into the 2000-2005 category of vintage allowances.[10]  The second explanation is that the year 2000 is the first year the more stringent Phase 2 emissions limitations become effective.  As a result, vintage 2000 allowances are a focal point for utilities' compliance planning purposes.  Utilities appear to transact in spot allowances to meet Phase 1 allowance needs and transact in early Phase 2 allowances to plan for Phase 2 allowance needs.  For example, there has been considerable swap activity between spot allowances and vintage 2000 allowances (Bartels 1997).  Moreover, because Phase 2 extends to virtually all electric generating units in the continental U.S., significantly more utilities are affected by Title IV starting in the year 2000 and must plan accordingly for compliance purposes, including allowance needs, in the year 2000.

The volume of arms-length allowances that have been traded in the forward market has given rise to readily available forward prices from intermediaries and other third party brokers.[11]  The next section lays out the term structure expected to be observed in a competitive and reasonably efficient allowance market.

### 3.  Theoretical Framework

In a world of certainty without transaction costs, if there is banking across all relevant periods, then arbitrage between current and expected future compliance costs and between allowances of differing vintages will cause the immediate settlement prices for allowances of different vintages to be equal.  In all periods, an individual holder of allowances chooses a level of $SO_2$ abatement such that the current marginal cost of abating in that period equals the current price of a spot

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[**] Vintage "Spot" = 1995 vintage allowances during 1993, 1994 and 1995; Vintage "Spot" = 1995 and 1996 vintages during 1996; Vintage "Spot" = 1995, 1996 and 1997 vintages during 1997.

[10] From 1993 through 1996, 100,000 allowances were offered for sale in the seven-year advance auction (vintages 2000 to 2003 respectively).  From 1994 through 1997, because of the operation of the "Direct Sales Reserve" provision of the law, 25,000 allowances were offered for sale in the six-year advance auction (2000-2003).  Because the EPA closed down the "Direct Sales Reserve" beginning in 1997, the 25,000 allowances involved were included in the 1997 seven-year advance auction, which accordingly involves 125,000 vintage 2004 allowances.

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market allowance ($MC_t=P_t$). Across any two periods with banking, the individual abates so that the discounted marginal cost of abatement is equal ($MC_t=MC_{t'}$). Since the discounted marginal cost of abatement is equal across periods and current marginal cost of abatement is equal to the current allowance price in every period, the immediate settlement prices for allowances of differing vintages are equal ($P_t=P_{t'}$). That is to say, allowances of differing vintages should sell for the same price today. For example, the immediate settlement price for a vintage 1996 allowance in 1996 should equal the immediate settlement price of a vintage 1997 allowance in 1996. This also implies that the spot price of an allowance should grow at the rate of interest when banking occurs between period t and period t+1, *ceteris paribus*.

The allowance market, though, is marked by uncertainty and positive transaction costs. One source of uncertainty is the cost of compliance. As a result, a firm may desire to revise its $SO_2$ emissions should abatement costs turn out to be different than expected. Second, actual emissions of $SO_2$ are stochastic even when abatement costs are certain, and thus, a firm's need for $SO_2$ allowances is stochastic. For these two reasons, $SO_2$ emissions in any given compliance year cannot be known with absolute certainty.

The allowance market is also marked by positive transaction costs, though the magnitude of these costs have declined over time. One cost is the commission fee paid to the market maker or broker for rendering his services. Commissions per allowance averaged $1.75 in mid-1994, $1.00 in late 1995, $0.75 in September, 1996, and $0.50 in early 1997. The latter figure was less than one percent of the prevailing spot price. A second type of transaction cost is the search costs incurred from deciding which broker to use and the search costs incurred if the firm decides instead to act as its own broker. A third transaction cost is the cost of having to negotiate a contract and the accompanying terms of sale. Search costs may decline over time as firms become more experienced with executing transactions in the allowance market.

Because $SO_2$ emissions in any given year are uncertain and it is costly to purchase and sell allowances, a firm benefits from holding a stock of allowances on hand to buffer itself against unexpectedly high $SO_2$ emissions. The benefit that accrues from holding a stock of allowances on

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[11] Of course, readily available forward prices is also likely to give rise to more forward allowance trading activity.

hand, called a convenience yield[12], is the transaction cost saved from not having to make additional transactions and/or undo the transaction just done.[13]  To the extent that there is uncertainty and positive transaction costs, allowances of different vintages will not sell for the same price today.

A model incorporating convenience yields generates weak backwardation in the term structure of allowance prices.  The return on the risk-free portfolio of holding an allowance and shorting a forward T periods is the sum of the forward price ($F_T$) less the spot market price today ($P_1$) plus the convenience yield ($CY_T$):

$$(F_T - P_1) + CY_T . \tag{1}$$

Since the portfolio is risk-free, its return must equal the risk-free return.  The risk-free return is the return from selling the allowance on the spot market today and subsequently investing that money in an asset with a certain return, such as a Treasury bill, until period T:

$$r_T P_1 , \tag{2}$$

where $r_T$ is the rate of interest between today and period T.  Equating (1) and (2) and rearranging gives:

$$\frac{F_T}{(1 + r_T)} + \frac{CY_T}{(1 + r_T)} = P_1 \tag{3}$$

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[12] Wright and Williams 1991.

[13] For the case of undoing the transaction just done, consider the example of the firm which sells off all unused 1995 allowances in 1995 (technically, it would be at the end of the "true-up" period on 31 January 1996), and then finds itself with unexpectedly high emissions in the following year - due to unexpectedly high costs or just the stochastic nature of $SO_2$ emissions in general.  The firm must now return to its broker (or find a trading partner) and repurchase allowances, incurring the same set of transaction costs a second time.

Rewriting equation (3) in terms of the discounted forward price $f_T$, the discounted convenience yield $cy_T$, and the spot price gives:

$$f_T + cy_T = P_1 \qquad\qquad (4)$$

For any positive convenience yield then, allowance prices will be weakly backwardated: $f_T < P_1$. For example, a positive convenience yield will cause the immediate settlement price for a vintage 1996 allowance transacted in 1996 to be greater than the immediate settlement price of a vintage 1997 allowance transacted in 1996. An immediate settlement price is the price paid today for the purchase of an allowance today.

As the convenience yield declines toward zero, because uncertainty in the allowance market resolves or transaction costs decline toward zero, allowances of different vintages will sell for the same price today: $f_T = P_1$. For example, if the convenience yield equals zero, then the immediate settlement price for a vintage 1996 allowance transacted in 1996 should equal the immediate settlement price of a vintage 1997 allowance transacted in 1996.

## 4. Empirical Evidence

Monthly immediate settlement prices for current and future vintage allowances published by Cantor Fitzgerald Environmental Brokerage Services, an intermediary in the $SO_2$ allowance market, can be used to assess the term structure of allowance prices. The immediate settlement (year t) price for a current vintage allowance (vintage year t) is a standard spot market price. Because a vintage year t+T allowance is not first usable until year t+T, immediate settlement transactions in year t involving allowances with vintage years greater than the current year can be thought of as a T year forward contract with the date of settlement being the vintage year.[14] For

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[14] In a standard forward market transaction a price, valued in *year T dollars*, quantity, and settlement date (*year T*) are agreed upon today by the two parties; transfer of the money and asset occurs on the settlement date (*year T*). Because a vintage year T allowances is not first usable until year T, an immediate settlement agreement for a vintage year T allowance can be thought of as a T year forward contract where the transaction price is a discounted futures price. In the interpretation of an immediate settlement transactions involving allowances with vintage years greater than the current year as a forward transaction, a price, valued in *today's dollars*, quantity, and

example, the immediate settlement transaction of a vintage 1997 allowance in the current year, say January 1996, can be thought of as a 1 year forward contract with a date of settlement in 1997. The immediate settlement price in year t for a vintage year t+T allowance is a discounted future price.[15]

Figure 1 shows that the immediate settlement prices of different vintage allowances are roughly equal over periods for which banking is reasonably expected to occur.[16] Each horizontal line on the Figure represents a single month of immediate settlement data for successive allowance vintages.[17] In Figure 1, horizontal lines marked by diamonds indicate that the monthly set of immediate settlement price data is from 1995, triangles indicate the monthly set of price data is from 1996, and squares represent monthly price data from 1997. Isolating a single horizontal line, discounted prices would be equal if the line is flat, that is, if the immediate settlement price for a 1996 allowance equals the immediate settlement price of a 1997 allowance, equals the immediate settlement price of a 1998 allowance, *et cetera*. This is in fact just about the pattern observed for immediate settlement price data in 1996 and 1997.
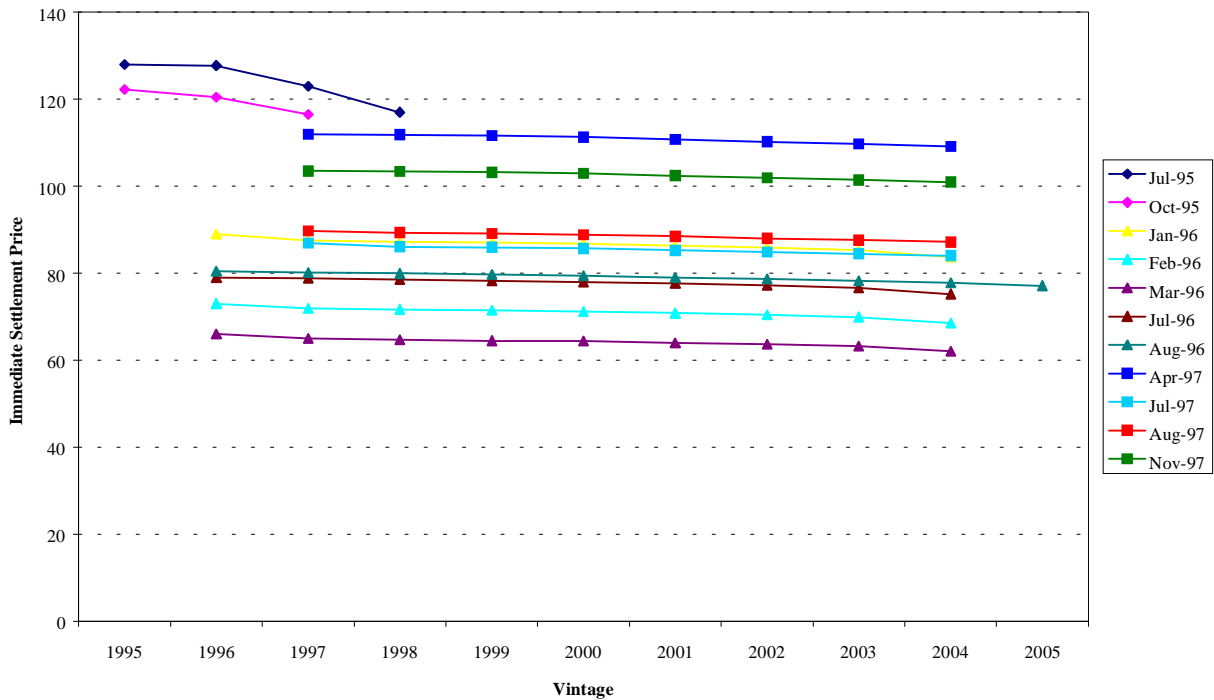
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settlement date (*today*) are agreed upon today by the two parties; transfer of the money and asset occurs on the settlement date (*today*).

[15] Similar types of forward transactions occur in the market for vintage wines. Wine is purchased today at a price denominated in today's dollars and the transfer of the wine from the seller to the buyer occurs today, but the buyer is not able to use the wine until some date in the future (i.e. when the wine matures or ripens).

[16] Estimates from Ellerman and Montero 1996 and those from the CEEPR questionnaire put the year in which the allowance bank in Phase I will be exhausted between 2004 and 2005. The CEEPR questionnaire is a survey distributed to utilities in the U.S. which are affected by Phase I of Title IV of the Clean Air Act of 1990. Responses came from 138 Phase I units, a response rate of 30%.

[17]Prices from every months of the year are not illustrated on Figure 1 so not to clutter the graph. Including data from all months of the year does not qualitatively change Figure 1.

**Figure 1**
**Immediate Settlement Prices, by Month**



The two immediate settlement price series from 1995 are more obviously tilted backward (i.e. the immediate settlement price of a future vintage year allowance is below the immediate settlement price of a nearer vintage year allowance). Though less obvious at the scale of Figure 1, 1996 and 1997 immediate settlement prices also exhibit some degree of backwardation.

Table 2 provides numerical evidence on the term structure of current and future vintage allowances. The Table shows the difference between the immediate settlement price of a spot allowance and the immediate settlement price of a forward allowance for several forward vintage years. As noted above, if the private market were frictionless and perfectly competitive, the difference between the immediate settlement price of a spot allowance and the immediate settlement price of a forward allowance would be zero. The smaller the differences shown in Table 2, the more closely the term structure of current and future vintage allowances conforms to the competitive, frictionless market ideal.

**Table 2**

**Difference Between Spot Price and Immediate Settlement Forward Price, By Month**

|  | Difference between spot and 1 year forward | Difference between spot and 2 year forward | Difference between spot and 4 year forward | Difference between spot and 7 year forward |
|---|---|---|---|---|
| July 1995 | 0.25 | 5.00 | -- | -- |
| Oct. 1995 | 1.75 | 5.75 | -- | -- |
| *1995 Average* | *1.00* | *5.36* | -- | -- |
| | | | | |
| Jan. 1996 | 1.50 | 1.75 | 2.25 | 3.75 |
| Feb. 1996 | 1.08 | 1.29 | 1.78 | 3.04 |
| March 1996 | 1.00 | 1.25 | 1.60 | 2.75 |
| July 1996 | 0.20 | 0.45 | 1.00 | 2.35 |
| Aug. 1996 | 0.30 | 0.50 | 1.10 | 2.25 |
| *1996 Average* | *0.81* | *1.04* | *1.54* | *2.82* |
| | | | | |
| April 1997 | 0.10 | 0.35 | 1.25 | 2.80 |
| July 1997 | 0.85 | 1.00 | 1.75 | 2.95 |
| Aug. 1997 | 0.39 | 0.61 | 1.27 | 2.55 |
| Nov. 1997 | 0.03 | 0.29 | 1.05 | 2.53 |
| *1997 Average* | *0.34* | *0.56* | *1.33* | *2.71* |

Table 2 illustrates several features of the term structure of current and future vintage year allowances. First, the magnitude of the convenience yield is quite small absolutely and quite small relative to the immediate settlement price of a spot allowance. For instance, on average in 1996, the immediate settlement price of a spot allowance was greater than the immediate settlement price of a one year forward allowance by $0.81, or 1% of the spot market price. Second, the magnitude of the convenience yield increases as the vintage of the forward allowance increases. That is, the convenience yield attached to holding a 1995 vintage allowance one year (as opposed to buying a 1996 vintage allowance in 1995) is smaller than the convenience yield attached to holding a 1995 vintage allowance two years (as opposed to buying a 1997 vintage allowance in 1995). This is reasonable since there is greater uncertainty attached to buying a 1997 allowance in 1995 as opposed to buying a 1996 allowance in 1995.

Finally, Table 2 demonstrates that the magnitude of the convenience yield, and therefore the degree of backwardation, has fallen over time. For example, in 1995 the average convenience yield attached to carrying a spot allowance for two years (as opposed to buying a 1997 allowance in 1995) was $5.36, in 1996 the average convenience yield was $1.04, and by 1997 this average convenience yield was $0.56. The decline in the convenience yield indicates a flattening of the term structure of allowances prices. The term structure of the monthly immediate settlement prices after mid-1996 is considerably flatter than the monthly immediate settlement prices in earlier months, approximating the term structure of allowance prices expected in a world of certainty with no transaction costs.

There are several explanations for the decline in the convenience yield over time, all which are consistent with the efficient market hypothesis put forth by JSB. First, the flattening of the term structure may reflect a reduction in transaction costs. As discussed above, transaction costs have fallen over time resulting in a decline in the penalty a firm must pay if the firm decides to revise its allowance needs in the future. A decline in transaction costs results in a decline in the magnitude of the convenience yield. In addition, the flattening of the term structure of allowances is consistent with increased market liquidity and the resolution of uncertainty about the value of current and future vintage allowances. The decline in uncertainty decreases the magnitude of the convenience yield. Finally, as compliance years pass, affected utilities are likely to have become more experienced in estimating expected $SO_2$ emissions and measuring actual $SO_2$ emissions. As a result, uncertainty over deviations from expected emissions is likely to have diminished over time. As uncertainty resolves, the benefit from holding a stock of allowances on hand to buffer against unexpectedly high $SO_2$ emissions decreases thereby decreasing the magnitude of the convenience yield. More likely than any single factor, it seems clear that the flattening of the term structure reflects a combination of all four factors.

## 5. Concluding Observations

It was clear to its proponents that the success of Title IV's innovative tradable allowance program for reducing sulfur dioxide emissions, like that of any tradable permit program, depended critically on the emergence of an efficient private market for rights to emit. The empirical analysis of the forward

market for sulfur dioxide allowances indicates that a relatively efficient forward market developed in a few years' time, by at least early-1996. This result is consistent with the hypothesis put forth by JSB.

When Title IV was first proposed, many observers argued that the conservative electric utility industry would never encourage the development of an efficient market for emission rights. This paper in conjunction with JSB has shown that these critics were wrong. Indeed, if the electric utility industry can so rapidly be engendered to participate in a market for $SO_2$ allowances, it is reasonable to expect that efficient markets for emission rights will be the norm as long as trading is permitted with few restrictions on when and how those rights can be traded.

# REFERENCES

Bartels, Carlton W. "Recent Trends in the $SO_2$ Allowance Marketplace." Mimeo, Cantor Fitzgerald Environmental Brokerage Services, January 22, 1997.

Ellerman, A. Denny and Montero, Juan Pablo. "Why Are Allowance Prices So Low? An Analysis of the $SO_2$ Emissions Trading Program." MIT Center for Energy and Environmental Policy Research, MIT-CEEPR 96-001 WP, February 1996.

Hahn R.W. "Economic Prescriptions for Environmental Problems: How the Patient Followed the Doctor's Orders." *Journal of Economic Perspectives*. 1989. 3.

Hahn R.W. and G.L Hester "Marketable Permits: Lessons for Theory and Practice." *Ecology Law Quarterly*. 1989. 16.

Joskow, Paul L. and Schmalensee, Richard. "The Political Economy of Market-Based Environmental Policy: The U.S. Acid Rain Program." *Journal of Law and Economics*, April 1998, 41 (1), forthcoming.

Joskow, Paul L., Richard Schmalensee, and Elizabeth M. Bailey. "The Development of the Sulfur Dioxide Emissions Market" *American Economic Review*, 1998, forthcoming.

National Economic Research Associates, *Key Issues in the Design of $NO_X$ Emission Trading Programs to Reduce Ground-Level Ozone*, Palo Alto: Electric Power Research Institute, EPRI TR-104245, July 1994.

Tietenberg, Thomas H. *Emissions Trading: An Exercise in Reforming Pollution Policy*. Washington: Resources for the Future, 1995.

U.S. Environmental Protection Agency (EPA), *1995 Compliance Results: Acid Rain Program*, project # EPA/430-R-96-012, Washington, DC, EPA, July 1996.

U.S. Environmental Protection Agency (EPA). *Acid Rain Program Update No. 3: Technology and Innovation*. Acid Rain Division, EPA 430-R-96-004, May 1996.

Williams, Jeffrey C., and Brian D. Wright, *Storage and Commodity Markets*, Cambridge, UK: Cambridge University Press, 1991.