Valuing Tradable Private Rights to Pollute the Public's Air

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Abstract

This study develops the economic rationale for the inclusion of new environmental financial assets, tradable pollution rights, in a well-diversified portfolio. These new assets are generated and their valuation determined in the market-incentive environmental regulatory approach called emissions trading, especially the cap-and-trade variant. This approach has been gaining wide acceptance and approval. A leading example is the sulfur dioxide market where tradable allowances are assets that may be held by private investors. Transactions in this market have reached volumes indicative of a high degree of liquidity. Comparable tradable rights in other pollutants are under active development. We explain the design and workings of these markets and demonstrate empirically, on the basis of time series data, that sulfur dioxide allowances have rates of return and yield distributions that make them candidates for inclusion in asset portfolios. We conjecture that other tradable pollution rights will exhibit similar properties when sufficient data are available. Financial analysts and accountants are likely to play an increasing role in advising investors about the role of these assets in a well-diversified portfolio.

Key Words: Tradable pollution rights, emissions trading, cap-and-trade markets, sulfur dioxide allowance, rate of return distributions, correlation and beta coefficients, diversified portfolio.

Data Availability

Sulfur dioxide allowance prices are from a publication of the Clean Air Market Division, U. S. Environmental Protection Agency, Washington, DC, 2003. These prices are based on reports from the Cantor Fitzgerald Environmental Brokerage Services and Fieldston Publications. Stock price and other indices are from published sources.

Introduction

The use of tradable private rights to emit pollutants, or emissions trading, as a government regulatory measure has become more generally acclaimed as a cost-effective policy instrument. However, some environmentalists remain unconvinced and believe there is perhaps trickery concealed in this decentralized market incentive measure compared with traditional prescriptive regulation. Even some business people and government officials remain skeptical, although the number is diminishing. Financial analysts may remain puzzled about the monetary value to be placed on this new right to pollute: is it a service, an asset, or what? This study is designed to show that there is no trickery involved, that the valuation methods applied to other goods and services apply with little modification in this case, and that tradable rights or emissions trading holds out the promise of cost-effective reduction of pollution in a number of interesting problem areas. Financial analysts and accountants are playing an increasing role in aiding businesses, as well as local and state governments, to make use of this innovative measure.

We first describe the history of this very recent interest in emissions trading that began as a serious matter in 1990 and burst into fuller bloom in the middle 1990s. We define and conceptualize a tradable private right to pollute showing the roles that the government and the markets play in creating and valuing this environmental commodity. Our focus is on the sulfur dioxide cap-and-trade market as among the earliest and now leading examples of emissions trading, although other markets are not far behind. There are a number of valuation methods of the tradable right that could be used, including the enterprise's willingness to pay for a tradable permit or the estimates obtained from the enterprise's marginal control costs of emissions. We elect to use the price of a tradable permit as determined in a competitive market as the measure of value. We explain how valuations emerge from the market and discuss how changes in the features and design of the market affect price determination.

No discussion of the performance of a market would be complete without a consideration of the confidence to be placed in the generation of the tradable right. We show that this confidence depends upon such factors as government monitoring of emissions and market rules. We also consider slippages and market imperfections so that investors can appraise their effects on tradable permit valuations. Our conclusion, based upon this work, is that these new assets are becoming a new and valuable addition to a more diversified investment portfolio.

How Decentralized Emissions Trading Evolved From Centralized Prescriptive Regulation

In 1970, with the support of the Nixon administration, path-breaking national environmental legislation was signed establishing clean air standards for six important pollutants and a U. S Environmental Protection Agency (U.S. EPA) to devise regulatory measures to attain these standards. As air quality is arguably our most serious environmental issue, we will concentrate on that area for our regulatory history and valuation examples, although emissions trading ideas are spreading to questions of water quality and availability as well as land usage.

The regulatory measures thought to be required at that time were of a centralized nature where the US EPA prescribed specific control technologies for all emitters limiting the rate of emission of a pollutant, or specified the acceptable rate of emission usually obtained by a particular technology. These were the measures that the U. S. Congress clearly had in mind, and consonant with what the public considered effective control at that time. There may have been some confusion in the public's mind that the installation of common control technologies on all emission sources would bring about zero pollution, although, in fact, these technologies could limit only the rate of emissions per unit time in the vast majority of cases. Since sources could operate over variable amounts of time, the total volume of pollution was indeterminate.

This centralized regulation, often referred to as prescriptive or command and control, did bring about improvement in five of the six air pollutants identified in the 1970 legislation as revealed in table 1. Despite this progress, only in the case of air-borne lead was the national ambient standard achieved. Furthermore, despite this advance, deep-seated problems in the use of centralized regulation were revealed. The U. S Congress was disappointed in the rate of achievement over time; the original regulation had envisioned more rapid progress to be reported in the five-year publications of the EPA. Also alarming was the fact that the marginal control costs of further reductions in these emissions were found to be increasing rapidly even though national ambient standards for most of these pollutants had not yet been achieved (Stavins 2000).

One problem was that the marginal control costs of emitters for a given amount of pollution were not equalized under centralized regulation since all emitters, with a wide variation of control technologies, were required to meet the same emissions limits. This equalization of marginal costs is a fundamental requirement for minimum aggregate control costs, as we shall show at a later point. Another problem was that prescriptive regulation placed a heavy burden on the U. S. EPA requiring a large staff to draw up control specifications, and monitor and enforce their use. Essentially, it appeared that the agency had to duplicate the environmental staffs of the enterprises being regulated leading to obvious tensions and problems. Consequently, administrative costs were increasing also.

Table 1
Changes in U. E. Emissions of Six Pollutants 1970 to 2002

	Emissions 1970 Millions of Short Tons Per Year	Percent Change 2002 Over 1970
Carbon monoxide	198	-40
Nitrogen oxide(s) (NOx)	23	-17
Volatile organic compounds (VOC)	36	-51
Particulate matter (PM10)	3	-34
Sulfur dioxide (SO2)	25	-52
	(Thousand Short Tons Per Year)	
Lead	3	-98

Source and notes: U. S. EPA. 2003. National Air Quality and Emissions Status and Trends Report. August. Further decreases in emissions are required of VOC and NOx, precursors of ozone, if ozone National Ambient Air Quality Standards (NAAQS) are to be achieved as currently 136 million people in the U. S. live in ozone non-attainment areas. Further reductions in SO2 emissions, one of the carriers of small particulate matter, are required in the U. S. as currently 59 million people live in areas not in attainment for PM2.5. These non-attainment areas, generally located in larger cities, vary in their concentrations of these pollutants so that precise estimates of the further reduction in precursor or carrier emissions that would achieve attainment in all areas are not possible.

The history of sulfur dioxide regulation provides a revealing inside story on these early efforts and their subsequent evolution. After the 1970 Act, the U. S. EPA, in response to neighborhood complaints about the emissions from electric utilities, required tall smokes stacks on all boilers to carry the pollutant away from the locality. The smokestacks did exactly that but carried the pollutant away where, in many cases, it descended on other areas in the region including neighboring Canada. Obviously, the complaints did not cease.

To try to deal more adequately with the problem, the next centralized regulation was the requirement that standard sulfur scrubbers be installed in the smokestacks. Scrubbers were required regardless of the sulfur content of coal burned for power or the location of the power plant. The utilities complained to congress that expensive scrubbers on existing plants would result in increased electric rates to consumers, not an appealing political consequence. The result was legislation that grand fathered many existing plants. Not surprisingly, utility managements found it profitable to run these older plants more intensively, maintain them beyond their expected lifetime, and postpone construction of many new plants that had to have scrubbers installed. As a consequence, sulfur dioxide emissions actually increased for a time during the 1980s.

The resultant pressures on and debate in the Congress, in the light of this history, deserves a fuller account than we can give here, but the passage of the Title IV of the Clean Air Act amendments of 1990 was a landmark piece of legislation for decentralized market-incentive control of a pollutant, in this instance, sulfur dioxide. The legislation mandated a pioneering national cap-and-trade market to reduce sulfur dioxide emissions in two phases by about half from historical levels of about 20 million tons per year. The objective was cost-effective pollution reduction, not zero pollution.

The main SO2 emitters, major electric utilities that burn coal, were required to participate in the program. While an aggregate emissions cap was specified in this program, no individual generating limit on emissions was required. Rather individual utility or generating units were allotted tradable allowances or permits to emit about half of their historical fossil-fuel heat usage (which could be translated into emissions). In a concession to secure utility support for the program, these allotments of valuable permits were free of charge. Several features of the allotment warrant attention. The commodity was a dated tradable permit good for the emission of one ton of sulfur dioxide and bankable for an unlimited period for future use. The fundamental rule of the market was that a utility had to turn over to the EPA a properly dated permit, either current or banked from prior allocations, during the year for every ton of emissions. Future allocations were assured, but future dated permits could not be used to cover current emissions. The permit becomes in fact a factor of production in the generation of electricity and derives its fundamental value from its government-mandated use to cover sulfur dioxide emissions.

Continuous electronic monitoring in the smokestacks of utilities assured that an accurate record of emissions would be kept, so important in maintaining the value of a permit. Recording devices were located in Washington where the whole program was managed by a very small staff of government officials (Kruger, McLean, and Chen 2000). There was no need for on site inspections other than to assure that equipment was maintained. Utilities were now free to make micro-decisions and to choose emission levels and control measures or devise new ones, to buy, sell or bank permits, and otherwise manage their portfolios.

Two types of accounts were set up to record transactions in and holdings of permits: a) Unit Account for the generating plant of a utility and a General Account for transactors of all types desiring to trade permits at any time during the year. This meant that investors, financial analysts, and others could buy, sell or hold such permits in addition to utilities. These transactors have included such financial firms as Morgan Stanley Capital Group, Inc., Bank One Capital Markets, ABN AMRO Inc., as well as individual investors and environmental groups. An increasing number of brokerage firms now offer services in the environmental financial asset field having grown from one or two in 1995 to 11 in 2003 (Clean Market Division, US EPA).

The US EPA, which tracks each allowance, handles many clearing and settlement matters of transactions reducing their appreciable transactions costs. As a result, transactions costs as measured by broker's fees declined over time and constitute no impediment to trading.

The market has witnessed a steady increase in the number of transactions and permits exchanged. Transactions increased from 215 in 1994 to 5,700 in 2002, and in that year the number of permits transacted of all dates, past, present, and future, increased to 21.4 million allowances. Over 9 million allowances of current and past vintage were held in permit banks at the end of 2002, about half in the Unit Accounts of utilities and half in the General Accounts of brokers, investors, and utilities (US EPA Clean Markets Division, 2003). These data indicate that the liquidity of the market has improved over time. The market has also succeeded in improving air quality by reducing SO2 emissions from 17.3 million tons nationally in 1980 to 10.2 million tons in 2002 (US EPA, Clean Air Market Division, figure 1, p. 2).

In order to facilitate price discovery, a small fraction of the allotted permits were withheld for a once-a-year public auction with net revenues returned to utilities in proportion to the amount of permits withheld. The Chicago Board of Trade offered to conduct the annual spring auctions free of charge and the first auction was held in 1993, two years prior to the official start of the program. However, the vast majority of transactions are now arranged outside the auctions through trader contacts or through brokers. The price per ton reported by a broker varied from a little less than \$150 in 1995 to around \$65 in 1996, then increased to over \$200 in 1999, and fluctuated around \$150 in 2003 (Cantor Fitzgerald 2003). The variance of price, its rate of return calculation, and other properties of the time series path of prices bearing on its attractiveness as an asset in an investor's portfolio will be described in a later section.

The SO2 cap-and-trade market is now regarded as a highly successful innovation and heralded as a model for other applications in the U. S. and abroad. A U. S. national cap-and-trade market for control of NOx emissions is well along in development. A local market is in operation to control stationary source emissions of volatile organic compounds in the Chicago ozone non-attainment area. The grand daddy of all cap-and-trade markets may arise from the Framework Convention on Climate Change and the subsequent Kyoto Protocol on limiting CO2 and other greenhouse gas emissions. These international negotiations have led to actions in Europe to constrain these emissions. While emission reductions have not yet been mandated in the USA, there has been developed a voluntary emissions trading market for limiting $CO2$ started by the Chicago Climate Exchange for a number of participating companies (Chicago Climate Exchange 2003). Markets for tradable rights to dispose of emissions of all kinds in the public's air are thus evolving and developing over time, generating a variety of environmental assets to be considered by investors.

What this means for accountants and financial analysts is that there is now a spectrum of tradable private rights to emit pollutants that may attract not only emitters interested in reducing costs, but also investors looking for assets that vary in yields and time paths in interesting ways from stocks and bonds. There should be increasing opportunities for financial analysts to provide consulting and other services to emitters learning the ropes of this new market incentive approach. While these tradable rights do not pay dividends or interest, they do bear a rate of return. Their current and future prices are amenable to analysis and may be compared to fluctuations in the prices and yields of other assets, as we shall show. What determines this price of a tradable right is an important question now to be addressed.

The Market Price of a Private Right to Pollute the Public's Air

We probe behind the descriptive statistics of the prior section to identify the demand and supply factors influencing price. The government determines an inelastic supply of permits issued each year that may be augmented by permits held in utility and investor banks. The demand for permits will depend upon current utility marginal control costs and transactions costs, and upon expectations of utilities and investors about future costs and changes in demand and policy. Ultimately the demand for $SO2$ allowances is derived from the government mandate that emissions must be covered by allowances turned over to the government by coal-burning utilities and the constraints on production processes that the mandate implies.

These major determinants of price may be usefully analyzed in diagrammatic manner. This exposition will also enable us to make more explicit the cost advantages of decentralized regulation compared with centralized or traditional regulation. The diagrams and detailed explanations are presented in Appendix A; a summary of the main results is presented here. Plausible assumptions that facilitate the analysis are that emitters are cost minimizing with respect to participating in the market, that they know the control cost functions for limiting emissions applicable to the various emission control options, and that markets are competitive. For cost savings to be realized these cost functions should vary among the individual participants. Costs would include the levelized real costs of various capital technologies such as scrubbers, afterburners, and carbon or liquid absorbers.

An anonymous referee has made the interesting suggestion that since an allowance presents an option or choice that can be used or banked that we develop an analysis in terms of the theory of option pricing. One difficulty we encounter with this approach is that a particular option is a financial contract with a specified future expiration date. The sulfur dioxide allowance has no future termination date and is therefore more akin to an exhaustible resource in price determination than an option (Ellerman 2000). That is, the government by determining the amount of pollution to be tolerated in the future determines the volume of permits that can be used now or at any time in the future. In equilibrium, all things equal, the price should rise as the rate of interest. Another difficulty we encounter is that the market has not yet developed liquid option or futures markets based upon the current allowance, although a forward contract market is underway. Were an option market to evolve making time series data available for testing, this analysis could be extended in that direction.

To return to our diagrammatic explanation of price formation, we note that under centralized or prescriptive regulation, as depicted in figure A1 in Appendix A, when each emitter is required to reduce emissions by the amount Oh, total control costs are the sum of triangles Ohb and Oha. The sloping lines are depictions of linear marginal control costs. In contrast, under the cap-and-trade market where both emitters equate marginal control costs to the equilibrium price, Op*, total control costs are the sum of triangles Oci and Ogd. Subtracting the latter from the former yields triangles dbf and fac, the positive savings in costs due to the market approach. It is immediately apparent why savings are positive; under decentralized regulation marginal control costs are equalized while under centralized regulation they are not. Marginal costs differ in the latter instance by the interval ba. Equilibrium price is that price in the market where purchase and sales are equal with no trader seeking additional transactions. In our illustrative two unit model that is achieved where df = fc.

The price of the tradable right is determined by the cap, by the marginal control cost functions of the participants, and by the efficient management of the portfolio of assets including tradable rights. The cap is a policy variable subject to change by the government as new information becomes available about the adverse impacts of pollution. A tightening of the cap affects the aggregate supply of rights and would increase the price, other things equal. Shifts of cost functions due to technological change would increase or decrease price as may be easily visualized in figure 2a. Inefficient portfolio management decisions either due to learning difficulties, lack of information, transactions costs, or other problems can also affect price.

Markets do not spring into being instantaneously or operate in a frictionless free state.

Behind the scenes of figure A1 are the policy decisions of the government on the cap and allotments, and the monitoring and enforcement procedures that create confidence in the tradable permit value among participants and market observers. Governments and private brokers have contributed to market efficiency by reducing transactions costs and by providing price information.

The results obtained so far on cost savings due to the cap-and-trade market pertain to cost minimization across space at one moment in time. To illustrate intertemporal cost minimization requires additional work and brings into the analysis important factors in the investment decision. Most cap-and-trade markets provide for banking of prior or current permits to facilitate cost minimization over time while prohibiting the borrowing from future allotments for current use since this could possibly lead to "spikes" in emissions with harms to human health, materials, and vegetation.

A requirement for control cost savings over time is that cost minimizing participants equate marginal control costs in each period with the period's expected price so that at equilibrium discounted marginal costs would be equal to current costs. This important point can be depicted in a simplified demonstration in figure A2 where an expected higher price for *t+1* can be shown to lead, for the low cost emitter, to an optimal positive bank, ik, in addition to the optimal sale in the current time period, hi.

A number of changes will affect the efficient time path of banking. These include changes in the government's cap as occurred in the SO2 market during phase II starting in 2000. What had been seen as excessive banking during phase I turned out to be rational in the light of the anticipated cap tightening (Ellerman and Montero 2002). Cost functions are subject to change; an expected upward shift would favor extra banking in the current period. Changes in product demand, composition of production inputs, and innovations in control technologies will also impact the time path of permit banks.

One of the advantages claimed of decentralized market incentives is that they can stimulate control measure innovations more so than traditional regulation where inertia and concerns about tightened regulation could inhibit control technology improvements. Under market incentives, such innovations as the increased use of low sulfur coal in the SO2 program in boilers previously thought ill adapted to that input had a significant effect on the permit price.

We shall present in the next section a statistical analysis of the properties of the observed time path of SO2 allowances that should be of interest to investors. In addition to rates of return, variability of these rates, and correlations of these yields with other assets, some investors may be interested in the implications of the capital asset pricing model (CAPM) for investment in environmental assets. In the realistic case of uncertainty, demand for permits and price become random variables and the CAPM may become appropriate for risk-averse participants to use to determine whether permits should be included in their diversified portfolio. The CAPM model provides information on this determination by equating the tradable permit price changes to the risk-adjusted discount rate, or

$$(r_p - r_f) = \alpha + \beta(r_i - r_f) \quad (1)$$

where $r_p = (p_t - p_{t-1}) / p_{t-1}$ is the monthly percent change in the price of the individual environmental asset, r_f is the monthly risk free asset return (assumed to be the t-bill), and r_i is the monthly return on an alternative diversified asset . If β was found to be not significantly different from zero it would suggest that holding a tradable permit as an alternative asset in a diversified portfolio is a viable choice. This would not be the case if β=1 since here the return to the environmental asset would fluctuate in the same manner as the diversified asset. We estimate the betas for sulfur dioxide allowances and provide a statistical analysis of the rates of return and variance of allowances over time and their correlation with other assets in the section that follows.

Lessons Obtained From a Statistical Analysis of Permit Prices

The valuations we are interested in emerge from actual markets and to the extent we have confidence in the competitive nature and regulatory framework of the market, the price of the tradable permit can answer a number of questions we have posed in previous sections. For the economist, the time series path of prices provides information about marginal control costs of the pollutant at the policy-set level of reduction. For the investor, the time series path of prices provides information about yields, variability, and correlation with other assets. This section applies a number of statistical tools to provide quantitative answers to questions about observable prices and their time paths that could be of value to the investor.

We start by presenting in table 2 the current tradable permit prices for the major cap-and-trade markets currently in existence or well along in development.

Table 2
Reported Prices (2002) of Tradable Permits for Various Substances Controlled in Cap and Trade Markets

Pollutant	*Price $*	*Cap Required Reduction*
NOx (SIP Call)	2,500 per ton	Varies by state (~35% by 2007)
VOM (Chicago)	529 per ton	12% from historical level
SO2	185 per ton	~50% from historical levels
CO2 (CCX)	.98 per metric ton	Increasing at 1% per year for ton carbon four years up to 10% over our years from firm benchmark

Notes: NOx = nitrogen oxides to be controlled by State Implementation Plans (SIP).

SO2 = sulfur dioxide controlled by the national emissions trading program mandated in the 1990 Clean Air Act Amendments. Prices obtained from Clean Air Markets-Allowance Trading. U. S. EPA, 2001. VOM = volatile organic materials (compounds) controlled by the Illinois EPA. Price obtained from Ill EPA Performance Report, 2002. CO2 = carbon dioxide to be traded in the voluntary market established by the Chicago Climate Exchange (CCX). Currently 21 participants agree to reduce their recorded CO2 emissions by 1% the first year increasing to 4% the fourth year, or 10% overall. Price as reported in the first auction of the program.

The wide variation in prices of these various pollutants tells us a good deal about the relative costs of reducing their emissions by the use of existing control measures given the current caps set by the government. These control technologies or measures range from changing inputs in the production processes, to redesigning outputs, installing scrubbers, afterburners, absorbers, and on to earning credits by sequestering carbon in newly planted forests. NOx emissions arise from boiler heat in the generation of electric power and require sophisticated adjustments to reduce emission volume. SO2 emissions result from the sulfur content of coal that can be managed by input substitution (low sulfur coal), scrubbers, and related control techniques. VOC emissions arise from numerous processes and may be reduced by a wide variety of afterburners, absorbers, changes in solvents, paints and the like. These control measures are in constant stages of developments. Investors considering holding tradable permits in their portfolio are well advised to keep informed about these control technology changes and about changes in government policies concerning the cap.

Table 2 does not provide information on the priorities to be assigned to reducing the various pollutants. For that purpose we require a ranking of the marginal benefits or reduction in damages brought about by the reduction in emissions. The most costly pollutant to reduce per ton may also be the one with greatest harms to health or damages to vegetation and materials. For purposes of this study the assumption is made that the emission reduction required by the cap (third column of table 2) balances benefits and costs, although this assumption does not hold for the evolving and incomplete market for CO2.

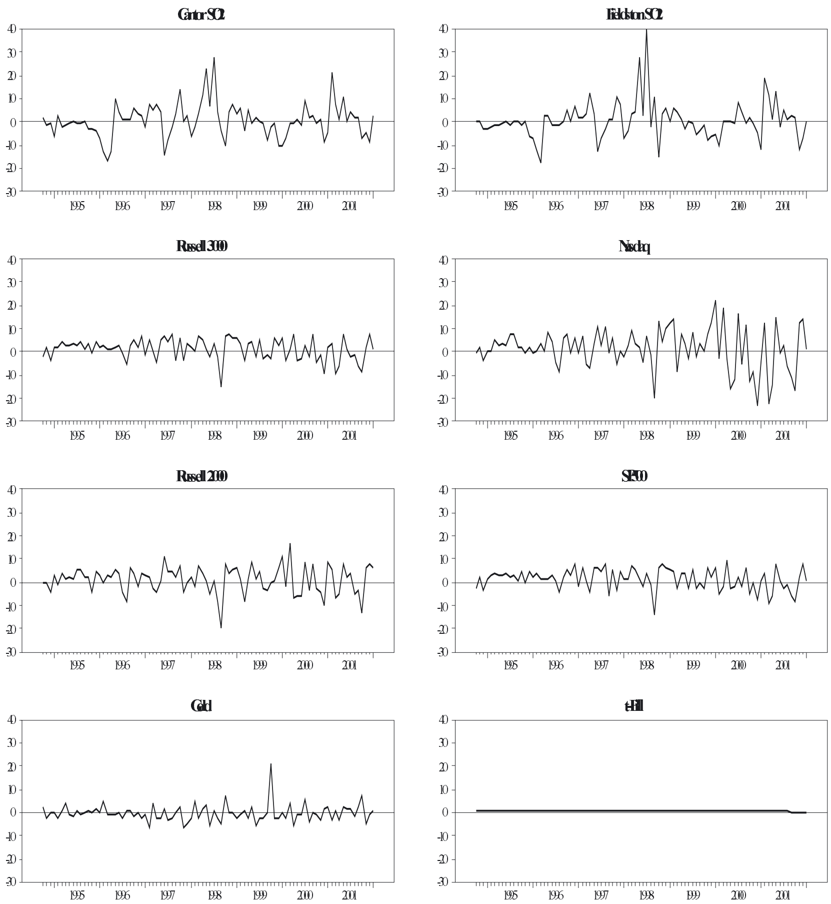
To repeat, the tradable permit is an asset priced in an open market and available to investors. While it does not yield a dividend or an interest rate, it does vary in monetary value. The questions therefore center on what roles tradable permits can play in the diversified portfolio. In addition to current prices, time series data on these prices would be invaluable in answering this question. As most tradable markets are new, there are limited time series data available for analysis. The longest running series are for the sulfur dioxide permit, which provides monthly observations for over seven years. The investor may well ask about the variation over time of this permit compared with various stock and bond indices, and the relative volatility of the permit compared with other assets. Of interest is whether the tradable SO2 asset is a viable alternative to more traditional investor assets based on a statistical analysis. To investigate this question we obtained monthly data on the NASDAQ, the S & P 500, the Russell 2000 and 3000, gold, and the risk-less t-bill for the period 9/1994 to 12/2001. As a measure of the SO2 market, we obtained the Cantor Fitzgerald SO2 and the Fieldston Publications SO2 price indices. The former SO2 index is based on transactions data observed by the brokerage firm and the latter is based on a small survey.

Based upon these indices we carry out our next statistical step by calculating and plotting the rates of return in figure 1.

Visual inspection of figure 1 indicates that changes in the SO2 prices series may have anticipated changes in environmental policy such as occurred when the cap was tightened in 1997 and 1998, and to other changes in control costs. SO2 allowance prices tended to be lower in the late 1990s when other assets were increasing rapidly but then tended to be higher in the early 2000s when other assets were falling. The impression is that the pattern is counter or non-cyclical reflecting in part the underlying demand for electricity. Changes in control costs such as occurred when deregulated railroads began bringing in low sulfur coal from the west likely affected allowance prices much more than the price of other assets. Visual inspection appears also to suggest a stickiness or autocorrelation in the SO2 series that deserves a more rigorous statistical analysis to which we will turn shortly.

To augment our visual impressions, we calculated a 12-month moving average that provides a more explicit investment guide. The mean return in percentages is .65 and .67 for the Cantor Fitzgerald and Fieldston respectively, the maximum is 7.4 and 7.8 respectively and the minimum is –5.2 and –4.0 respectively. This signifies that during this period, the investor would have been well advised to be active in the market rather than content to hold for the entire period. The longer run prospects, given the fixed supply of tradable allowances and the increasing demand for electricity due to economic growth, could point toward a trend of increasing allowance values down the road.

Fig. 1. Plots of monthly returns of various assets, in percent



Sources of data: Sulfur dioxide prices were available from the U. S. Environmental Protection Agency, Clean Air Market Program, SO2 Allowance Prices, October 2, 2003. They are based on reports of the Cantor Fitzgerald Environmental Brokerage Services and Fieldston Publications. Other time series data were provided by Professor Gilbert W. Bassett, Jr., Head Department of Finance, University of Illinois at Chicago from market sources in the public domain.

Our visual impressions that the environmental asset varies independently from other assets is confirmed in table 3 where we report correlation coefficients between these various assets. The large sample standard error of a correlation coefficient is $\sqrt{1/N}$ where *N* is the sample size (here 88) or 0.1066. This suggests that to be significantly different from zero at greater than or equal to 95% confidence, the absolute value of the correlation coefficient must be greater than 0.2132. The two SO2 returns are significantly but not perfectly correlated with each other (correlation coefficient of 0.82), but are not significantly correlated with the other assets at the 95% confidence level. This provides evidence about the contribution that the allowance can make in a diversified portfolio.

Table 3
Correlation of Rates of Returns of Environmental and Financial Assets

Financial Asset	Cantor Fitzgerald	Fieldston
S & P 500	0.10518	-0.08288
NASDAQ	0.08945	-0.07386
Russell 2000	0.01463	-0.18112
Russell 3000	0.08647	-0.11406
T-Bill	0.00093	0.01364
Gold	-0.07045	-0.06712

Note: None of the correlation coefficients are significantly different from zero at the 95% confidence level.

Sources: Data on the sulfur dioxide prices are reported by the Cantor Fitzgerald Environmental Brokerage Services and Fieldston Publications. Other sources are listed in figure 1.

Another way to investigate the relationship between SO2 series and market index series is to estimate the beta coefficients that we mentioned might be of interest to some investors. Table 4 presents the beta coefficient defined earlier for the SO2 allowance price changes obtained from a regression of monthly values on several market index yields. We find that none of the beta coefficients are significantly different from zero at the 95% confidence level. This may be interpreted as meaning that the return from holding SO2 tradable permits are generally not related to the returns from holding stocks. We conjecture that what holds for the SO2 permit will also be found to hold for other tradable permits, thus tradable pollution permits are an asset option for inclusion in a risk-diversified portfolio. Our analysis of the factors affecting the value of tradable rights—the cap, marginal control costs, and the management of the permits—reveal that they are significantly different from the factors affecting stock prices.

Table 4
Beta Coefficient Estimates for SO2 Allowances

Financial Asset	*Cantor Fitzgerald*	*Fieldston*
S & P 500	0.1730 (0.9818)	-0.1470 (-0.7722)

NASDAQ	0.0758 (0.8422)	-0.0659 (-0.6779)
Russell 2000	0.0198 (0.1424)	-0.2507 (-1.7013)
Russell 3000	0.1418 (0.8064)	-0.2012 (-1.0648)
Gold	-0.1415 (-0.6463)	-0.1460 (-0.6182)
Note: Numbers in parentheses are t-statistics.		
Sources of data as listed in figure 1.		

We have noted that visual inspection of figure 1 indicated to us some stickiness in the allowance pattern, which suggests that the active investor could, given adequate forecasting methods, predict price movements sufficiently to enjoy capital gains providing transactions costs could be covered. Such predictability would indicate that the SO2 market does not yet follow in every respect a random walk. This impression and resulting conclusion deserves a more rigorous statistical analysis that may be of value to investors.

This line of research follows a path breaking paper by Samuelson (1965) that specified the conditions for prices in a market to follow a random walk. If these conditions of competition and what are now called rational expectations on the part of traders are met, a properly anticipated series will fluctuate randomly. Recent developments in time series analysis provide new tools to test the possible random walk properties of a market in ways useful for an informed investment decision. The issue of predictability of a market price may be characterized as first moment memory, and can be statistically tested using the time series of SO2 allowance prices.

Furthermore, the prediction of changes in variability of a series, or second moment memory or predictability on which the Samuelson theorem is silent, could provide additional investment information.

In seminal work Engle (1982) argued that both the first and second moments of a series such as the SO2 allowance prices should be modeled to test moment predictability, and provided the basis for statistical tests of these two aspects of memory or predictability. We utilize the well-known ARCH/GARCH models to throw light on the existence of these properties in the SO2 case. More complete definitions of the methods and variables and a summary demonstration of the derivation of the models are given in Appendix B. Appendix table B1 presents the results in terms of the variables defined in the appendix. A brief non-technical summary of the results follows.

When examining table B1, we are immediately struck by the fact that all of the traditional financial assets except Gold and the Russell 2000 have no first moment memory meaning that these series are best predicted by their means only, as consistent with the random walk assumption. In contrast, the two SO2 assets have memory in the first moment, signifying that the alert investor may be able to forecast short-term price movements and enjoy trading gains. Such increased trading could add to the liquidity of the market and could over time eliminate the elements remaining of first moment memory.

The second moment models of all assets exhibit memory except the Cantor Fitzgerald SO2 and the S & P 500 time series models. As the Cantor Fitzgerald price series is the most complete record of an environmental asset at this time, we can extend our finding of no contemporary correlation between the SO2 assets and the traditional financial assets by noting that there appear to be quite different model structures across environmental and most other asset classes. In addition, the dynamic pattern of these assets is not similar. These results reinforce our contention that rational investors wishing to diversify should consider investment in environmental assets as part of a diversified portfolio.

An Analyst's Guide to Kicking the Market's Tires

To have confidence in the valuations that emerge from the emissions trading market and their properties compared with other assets requires more than information on the price, and resulting statistical analysis. The design and performance of the market, the characteristics of its participants, and the regulatory framework supporting market activity, present and future, are important aspects for any investor to consider. These markets are new and there is evidence that participants are undergoing periods of learning behavior that affect value as suggested by research on an urban cap-and-trade market designed to reduce stationary-source emissions of volatile organic compounds (Kosobud, Stokes, Tallarico, and Scott, in process). While the sulfur dioxide market is the most mature of present cap-and-trade designs providing the investor with the most information currently, the other evolving markets present opportunities for early gains. The alert investor will want to keep several other considerations in mind.

Monopoly or monopsony gaming of market transactions would affect prices and expectations of future price paths. The government's involvement in allotting tradable permits, in monitoring emissions, and in providing transparent information on allotments and transactions provides some assurances on this score. Perhaps more pressing is the problem of accuracy in recording of emissions. Inaccurate or misleading emission reports from participants would undermine the value of tradable permits. The continuous electronic monitoring of sulfur emissions from electric utility smokestacks provides assurance on this count in the sulfur dioxide cap-and-trade market. Other emission recording measures such as the content of inputs or the recording instruments on processes within the facility are less reliable and require government monitoring that can be expensive. From our experience with the Chicago trading program, we have found most errors in emission reporting to be minor recording problems and not systematic efforts to under report emissions. An active role for government in monitoring and enforcing market rules seems required, and unavoidable, if confidence in permit prices is to be maintained.

Although all markets are subject to varying degrees of government regulation, emissions trading markets have been created by government legislation and design and call for more thorough monitoring and enforcement. Design of the permit and banking provisions, determination of allotments of credits, accounting for emissions, monitoring of market rules, and specification of enforcement procedures, all entail government action. Tradable permits look and behave like private property but governments have reserved the right to revise them and their allotment depending upon new information on the harms of pollution. However, there is no evidence of any proposal or consideration being given to treating environmental assets as being any different from other assets. In fact, there appears to be an effort to reduce concerns on this score to the point where they may be more secure from manipulation than some other stocks and bonds.

Despite the early skepticism and uncertainty about the viability of market incentives as an environmental regulatory measure, the evidence increasingly indicates that a cost-effective and workable tool has been created in the markets established to date. Our statistical study provides much evidence that the observable price path of the environmental asset exhibits different properties from other assets making SO2 allowances a serious candidate for inclusion in a diversified portfolio.

Other applications both in the U. S. and abroad are in the making, including the market that would be the grand daddy of them all, the CO2 market. Private brokers are entering the market to assist in transactions, and in developing derivatives based on the spot permits. A consulting service industry is in the emerging stage. Emissions trading is in an early stage of evolution and well worth serious study, in our view, by a wide variety of observers, including accountants and financial analysts.

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Appendix A. Illustration of the Cost-Effectiveness of a Cap-and-Trade Market

Simple figures will demonstrate the cost-effective advantages of emissions trading compared with prescriptive regulation. Figure A1 presents the linear marginal cost functions for two participants as they reduce emissions from 0 to 100%. These linear functions are, of course, a rough piece-wise approximation to the control costs of various options beginning with the cheapest option first. The curves could rise sharply with reductions but nothing is lost at this stage by our assumption of linearity.

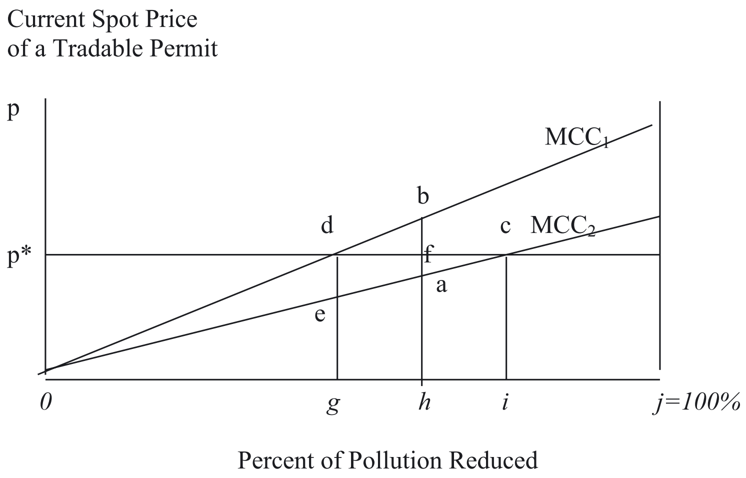

Figure A1. Price determination and optimum transactions in the current period.

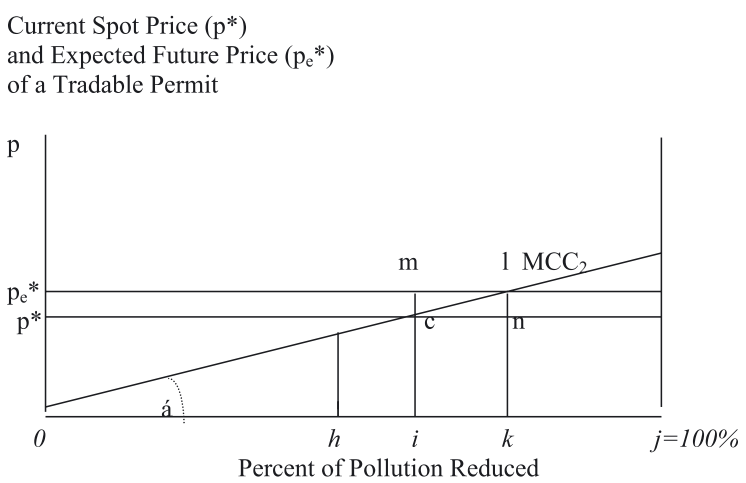

Figure A2. Optimal bank, ik = b^0, determination in the future period.

Note that we assume that the curves differ in slope, a requirement for cost savings. That is, for the cap and trade market to achieve savings, it is required that marginal costs of control vary among participants. Most empirical studies find cost variation due to the many participant differences such as size, production functions, outputs and inputs, and management and emissions control measures available. We shall assume that the two participants in figure A1 have the same volume of emissions at 100% and make decisions in a competitive market. It is straightforward to generalize to many participants with different volumes of emissions.

Under traditional regulation, the government would impose a limitation on emissions, say a 50% reduction, for both participants requiring them under normal circumstances to reduce by the interval 0h in figure A1. The total control costs for both participants may be estimated as the areas under their curves assuming that they choose the cheapest measures to achieve the reduction. For participant 1 their total cost would equal the triangle 0hb controlling emissions below point b and emitting above. For participant 2 total cost would equal 0ha. Total costs for the two would equal the sum of the triangles, and for the market as a whole we would sum under the curves to the 50% reduction point to estimate aggregate control costs. This gives us a measure of the use of resources to achieve improved environmental air quality and it also provides a measure of the charge on emitters for access to disposing of a unit of emissions in the public's air. It is important to note that marginal control costs are not equalized across emitters at the 50% point.

Under decentralized emissions trading with the same goal of a 50% reduction, the government now allots to each participant 50% of their total emissions in the form of dated tradable rights. The government may auction off a few rights to establish price discovery. But even without an auction, alert participants will realize the gains from trading. Participant 2 could reduce by more than 50% and sell rights to participant 1 who would find it cost-effective to buy rights and reduce by less than 50%. At the equilibrium price the number of rights sold must equal the number bought with no further transactions desired. In our example purchases measured by the interval df must equal sales measured by the interval fc. This balance occurs at the one and only equilibrium price of p*.

Equating marginal costs with the equilibrium price minimizes control costs for both participants. Participant 1 has reduced emissions by 0g and participant 2 by 0i. At price p* neither would find it cost effective to engage in further transactions. At equilibrium, the participants are reducing by different amounts but their marginal control costs are equal, a requirement for minimizing total control costs in a cap and trade market. Also aggregate emissions have been reduced by 50%. The argument generalizes to more than two firms and to integrals under nonlinear cost curves.

Aggregate control costs may be compared for centralized and decentralized regulation in figure A1. The total control costs under the latter are the sum of the triangles 0gd and 0ic estimated as before. Under the centralized regulation total costs were triangles 0hb plus 0ha. While participant 2 has increased costs measured by the trapezoid ahic, participant 1 has decreased costs by the larger trapezoid ghbd. Only a little geometry is required to estimate the cost savings of the cap and trade approach compared with traditional regulation to be the triangles acf plus dfb. The relative size of the triangles indicates which participant gains most from trading, which in turn depends upon the relative slopes of the curves. The value of a private right to pollute by one unit of emissions is now the equilibrium price p*.

It is easy to visualize in figure A1 the effect on equilibrium price of a change in the cap. If the government were to decide to tighten the cap, say to 75%, the allotments of tradable rights would be less and the equilibrium price would increase as we move up the marginal control cost curves. Market incentives are believed to stimulate control innovations made by participants that can add to their gains from trades. Under traditional regulation there is both inertia on this count and the risk that allowable emission rates could be lowered. In figure A1 if we rotate the curve for participant 2 downward to illustrate an innovation, we can see that the equilibrium price would be lowered. If both participants were to innovate the price would again be lowered but by a larger amount. The gains of innovation are not only those realized by the participants, but are also gains for the public in the decrease in the resources used to control pollution.

To achieve inter temporal cost minimization requires that the cap and trade market include dated tradable rights that can be banked for future use so that variations in price ranging from current to expected future prices could play a proper role in managing emissions and transactions. The most theoretically complete banking provision in the market would be the ability to store currently issued tradable rights for as long as desired and the ability to borrow tradable rights from future issues. Borrowing is not permitted in figure A2. The fundamental rule of the market is now changed so that participants can cover current emissions with current permits or permits of prior dates. This would allow equating of current and expected marginal costs, a requirement of inter temporal cost-minimization.

The savings in control costs to be achieved from banking for one future scenario may be illustrated in figure A2. Restricting our attention to positive banks, because negative banking or borrowing from the future is not permitted by the market design, the optimum bank may be calculated in the following way. The marginal cost curve is redrawn without change for the future period for participant 2. An expected future price, p*(e), is drawn for the next year and is assumed to be above the current price, p*, due to changes in demand or policy with respect to the cap.

Participant 2 will find it cost effective to further reduce emissions by the interval ik and bank the currently issued tradable credits for use in the next period. There are benefits and costs to this decision. The benefits of sales next year are measured the rectangle iklm. The present discounted value of that amount is obtained by dividing by one plus the current interest rate, r. The present costs of that decision may be estimated in the increased costs of reducing emissions measured by the trapezoid iklc. Net benefits are iklm/(1+r) – iklc. The areas may be converted into more meaningful variables and the optimum bank determined as follows.

The rectangle iklm is equal to the banked amount, ik, times the height of the rectangle or p_e^*. Let the amount banked, ik, equal *b*; thus gross revenues from banking are:

$$Revenues = bp_e^* / (1/r_i) \qquad \text{(A1)}$$

The trapezoid iklc as a measure of the cost function is a little more complicated. The rectangle part, ikcn, may be represented as bp^*. The remaining part, or triangle, converts to ½ of (cn)(nl). In turn this may be converted into ½ of bln, as cn = ik = *b*. To get a useful expression for ln, we note that the slope of the marginal cost curve can be represented as α=ln/cn, or a=ln/*b*. Hence, ln = αb. The triangle now becomes $.5\alpha b^2$. Putting both terms in the cost function together yields:

$$Costs = bp^* + .5\alpha b^2 \qquad \text{(A2)}$$

Net revenues are Revenues – Costs. Given our well behaved functions, the optimum bank is the partial derivative of net revenues with respect to *b* which, when solved for the optimum,b^0, yields with a little rearranging:

$$b^0 = \alpha p_e^* / (1 + r_i) - p^* / \alpha \qquad \text{(A3)}$$

This equation may be interpreted to mean that the optimum bank depends positively upon the expected future price and negatively on the current price. The slope of the marginal control cost exerts an interesting effect. An increase augments banking and future revenues and also acts to reduce the negative effect of current price. To the extent market incentives induce innovations and lower the slope of the marginal cost curve for many participants, they also act to reduce the incentive to bank.

Appendix B. Statistical Analysis of the Predictability of SO2 Allowance Prices

There is no predictability in the next period in the case of a market exhibiting the well-known random walk. The basis for understanding the necessary conditions for a market price series to exhibit a random walk was greatly extended by work of Samuelson (1965) who showed that a properly anticipated series (the first moment) would fluctuate randomly. In this case the first moment cannot be predicted, as it has no memory. The basis for the proof is the observation that if an expectation is expected to change, it cannot be rational. If an expectation of a price (or a detrended price) is rational then $E(P_{t+!}) = E(P_t) + \varepsilon_{t+1}$ where ε_{t+1} is the unknown shock occurring in period t+1. The conditions for this theorem holding include having a fully functioning and liquid market and rational expectations on the part of the participants. Samuelson's theory leaves as an open question whether the volatility or second moment of such a price series is constant or whether it has memory (can be predicted). In order to investigate this further and contrast the SO2 market with the market for other assets we now turn to the popular ARCH/GARCH models. ARCH stands for autoregressive conditional heteroskedasticity and GARCH stands for generalized autoregressive conditional heteroskedasticity. In seminal work Engle (1982) argued that both the first and second moment of a series should be modeled. The models can be estimated jointly with maximum likelihood or using the two pass method where the residual of the first moment model is squared and modeled again in the second pass. The purpose of estimating the second moment model is to investigate whether the squared residual (a proxy for the conditional volatility on the model) is predictable. Using the lag operator notation that $L^j x_t \equiv x_{t-j}$, where x is our subject series, the GARCH model can be written as

$$\begin{aligned} \phi(L)x_t &= \theta(L)e_t \\ \delta(L)\hat{e}_t^2 &= \gamma(L)u_t \end{aligned} \qquad \text{(B1)}$$

where $\phi(L)$ is the first moment autoregressive term, $\theta(L)$ is the first moment moving average term, $\delta(L)$ is the second moment autoregressive term and $\gamma(L)$ is the second moment moving average term. The first moment residual is e_t while in the second moment equation we are estimating $\hat{e}_t^2$ which has an error term u_t. If $\delta(L)=1$ then we have an ARCH model. By selecting the two pass method of estimation and using automatic model detection software, we limit the possibility that we have in some way selected our model with a hidden bias. The one pass method of estimation involves jointly estimating both equations in (B1) and cannot be done automatically. In essence, we fit the widely used Box-Jenkins ARIMA models to both the first and second moments.

Table B1 reveals that the Cantor Fitzgerald series in the first SO2 equation exhibits significant first moment predictability at the 95% confidence interval at the first and second period lags of the error term. The Fieldston series exhibits first moment predictability at the second and seven period lags of the error term. The Russell 2000 series exhibits first moment predictability as does the gold series. The S & P 500, NASDAQ, and Russell 3000 series follow a random walk and therefore have no first moment memory as revealed in table B1. All the series exhibit second moment memory or predictability except for the Cantor Fitzgerald SO2 series and the S & P 500 series.

Table B1
ARCH/GARCH Models for Selected Financial Assets

Cantor Fitzgerald: $r_p = 0.4936 + (1 + 0.373L + 0.2391L^2)e_t$ $(e_t)^2 = 45.71 + u_t$ (.42) (-3.53) (-2.25) (4.29)
Fieldston: $r_p = 0.4981 + (1 + 0.4584L^2 + 0.3656L^7)e_t$ $(e_t)^2 = 47.78 + (1 + 0.4988L^2)u_t$ (.37) (-5.30) (-3.99) (3.07) (-5.33)
S & P 500: $r_p = 1.256 + e_t$ $(e_t)^2 = 20.24 + u_t$ (2.60) (5.86)
NASDAQ: $r_p = 1.467 + e_t$ $(1 - 0.9931L)(e_t)^2 = 169.9 + (1 - 1.090L - 0.0043L^2)u_t$ (1.55) (27.34) (0.202) (55.21) (-.09)
Russell 2000: $(1–0.7643L)\ r_p = 1.071+(1-0.9134L)et$ $(1-0.9448L)(et)^2 = 34.98+(1-1.029L)u_t$ (4.92) (3.57) (8.94) (29.76) (1.96) (18.20)
Russell 3000: $r_p = 1.208 + e_t$ $(1 - 1.006L)(e_t)^2 = 38.50 + (1 - 1.070L)u_t$ (2.494) (30.68) (.21) (253.2)
Gold: $(1 + 0.6705L)\ r_p = -0.2659 + (1 + 0.5553L-.5429L^2)$ $e_t(e_t)^2 =10.48 + u_t$ (-6.06) (-1.25) (-6.13) (4.92) (2.65)
Note: All models estimated using automatic model detection. $(e_t)^2$ is the residual from the first moment equation. Model estimated using two-pass method suggested by Engle(1982) as specified in equation (3). Data sources as described in figure 1. ARCH stands for autoregressive conditional heteroskedasticity and GARCH stands for generalized autoregressive conditional heteroskedasticity. Variables defined in appendix B.

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