Design Issues for a CO2 Market

John E. Parsons
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MIT Finance Lunch Seminar

MIT CEEPR
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Outline

- Preview of the Key Design Issue
- Institutional Background on CO2 & Emissions Markets Generally
- Top Level: Optimal Mechanism Design for Stock Pollutants
- Drill Down: Assuring Liquidity in Emissions Markets
- My Questions

Preview of the Key Design Issue: P v Q

- Optimal Regulation: Control Prices or Quantities
  - in the face of uncertainty about costs and benefits
- Weitzman (1974) – optimal instrument depends upon the relative slope of the marginal benefit and marginal cost functions
  - sharply sloping marginal benefits » quantity controls
  - sharply sloping marginal costs » price controls
- Application to CO_2 & global warming by Nordhaus (1994), Pizer (1998, 1999, 2002), Hoel & Karp (2002), Newell & Pizer (2006)
  - greenhouse gasses are "stock pollutants"
  - for a stock pollutant the marginal benefit curve is flat relative to variation in annual output, while the marginal cost curve is steep in annual output
  - stock pollutant » price controls
- Mapped to a debate between…
  - price control » carbon tax
  - quantity control » carbon cap & trade system

Institutional Background

- Existing emissions markets…
  - US SO2 market
    - Initiated in 1993 under the first President Bush – Schmalensee on the CEA.
    - Covers major point sources only.
    - Emissions are currently capped at approx. 8.95 million tons annually, <50% 1980 levels.
    - Before 2004 the price of an allowance was roughly $200/ton » total asset value of $1.8 billion annually available for use or trade.
    - Allowances were distributed free to incumbent sources except a small annual auction.
    - Freely bankable through time.
    - Positive reputation…at least until recently.
    - Trade has primarily been OTC using a small pool of brokers; exchanged traded futures are recent; turnovers registered w/ EPA approx $1-2 billion/year.
  - Mutiple US NOx markets
    - Much smaller.
    - Major disruption tied to the California electricity crisis.

Institutional Background (cont.)

- CO_2 markets…EU-ETS
  - First, trial phase, 2005-2007: Second phase (first Kyoto period) 2008-2012.
  - Covered >10,000 installations in the EU-27 countries:
    - primarily electric power and heavy industry, notably metals, refining, cement, pulp&paper;
    - excludes household and transportation;
    - only one component of Kyoto compliance;
    - coverage being extended to air transport and shipping.
  - Emissions initially capped at 2.1 billion tons annually,
    - which is €42 billion valued at €20/ton;
    - ≈2.5-5% less than if unconstrained;
    - reduced to 1.9 billion tons in second phase.
  - System is administered nationally, but allowances are freely tradeable throughout the EU.
  - Allowances were distributed free to incumbent sources with the exception of a few small auctions; auctioning is to expand to 60% in second phase.
  - Freely bankable within the phase. No bankability across phases, creating a seam at 07/08.
  - Trade is both OTC and through exchanges. Futures are actively traded.

Institutional Background (cont.)

CO2 Prices in the EU-ETS

Institutional Background (cont.)

- CO_2 markets…Kyoto trading mechanisms
  - Hot air
    - Unused Russian emission allowances can be sold to, e.g., Japan or Canada.
  - Clean Development Mechanism (CDM)
    - Enables industrialized countries to meet their Kyoto emission reduction obligations for 2008-2012 through projects in developing countries.
    - E.g., project in China offsets Italian reduction obligation.
    - UN agency must validate the project based reductions.
    - The EU has linked the CDM to its EU-ETS, giving CDM projects a market price.
  - Joint Implementation
    - Similar, but can be between Annex 1 countries
- CO_2 markets…the US state level
  - California – full, expansive authority, but mechanisms being designed
  - Northeast US – cap & trade for electric power, <90% by 2018
    - First auction scheduled for Sept 25, 08

Institutional Background (cont.)

- CO_2 markets…the US Federal Government
  - Lead cap & trade bill … McCain-Lieberman, morphed to Lieberman-Warner, to Boxer- Lieberman-Warner
    - Killed summer ’08
    - Comprehensive coverage of all sectors, including transportation and household and all gases.
    - Relative to 2005 emissions, caps at
      - 96% in 2012,
      - 81% in 2030 and
      - 29% in 2050.
    - Free allocations initially, phasing out to 100% auctions in 2031
    - Estimated value of $287 billion annually @$40/t (2005$),
      - $3,580 per family of 4 = 15% of non-CO_2 Federal revenue
      - CO_2 charge per gallon of gasoline = 39¢.
    - Free banking, some borrowing with frictions; carbon market efficiency board.
  - Main alternative includes a safety-valve…
    - @$7/t escalating in time.
  - Economist’s hobby horse: a carbon tax

Top Level: Optimal Mechanism Design for Stock Pollutants

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Context

- Cap & Trade vs. Carbon Tax… Quantity vs. Price Controls

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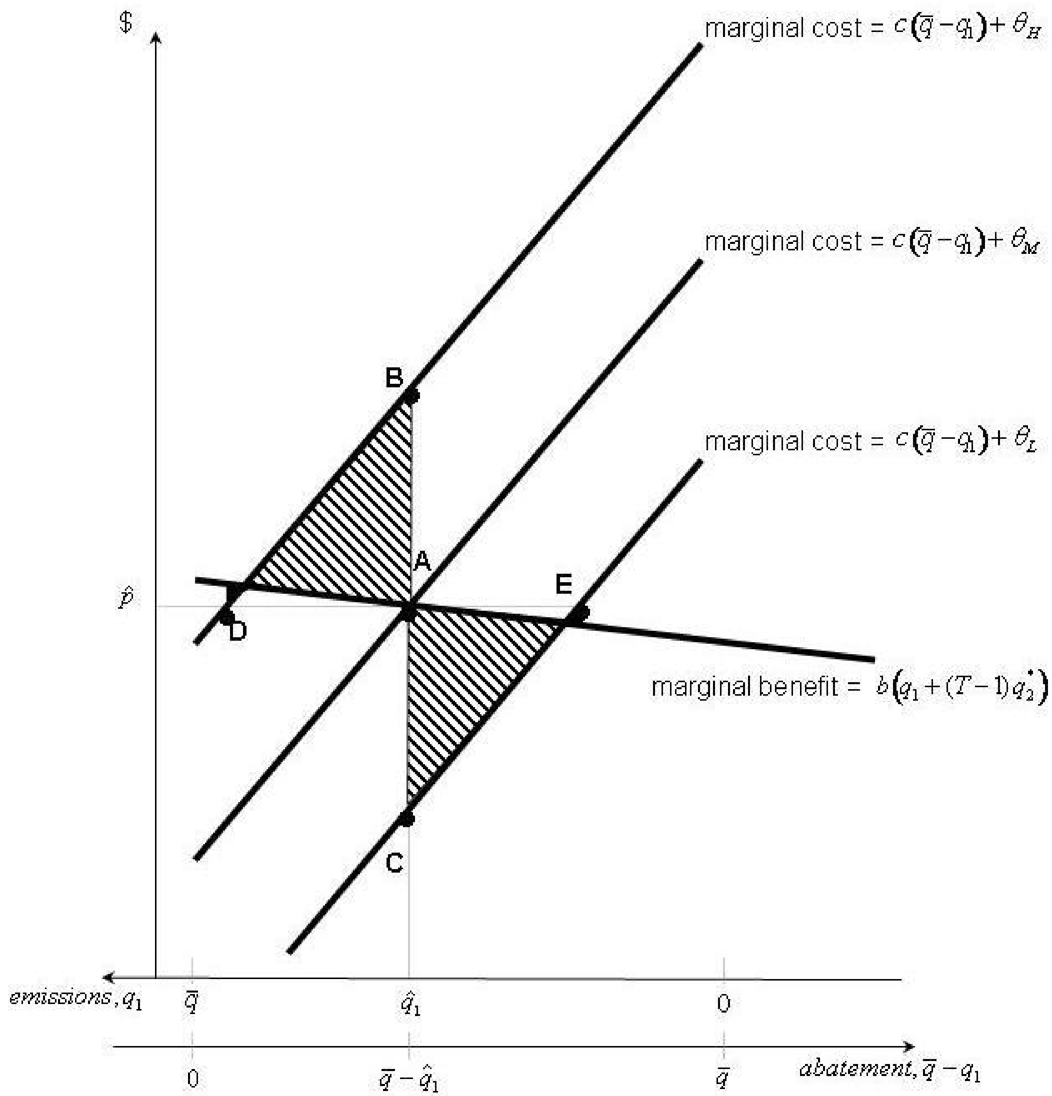
- Weitzman: Uncertainty About Costs and Benefits

Marginal Costs and Marginal Benefits of Abatement ala Weitzman (1974)



Context

- Cap & Trade vs. Carbon Tax… Quantity vs. Price Controls
- Weitzman: Uncertainty About Costs and Benefits
- Stock Pollutant Argument

Analysis of Carbon as a Stock Pollutant ala Nordhaus/Pizer/Stern/Tirole

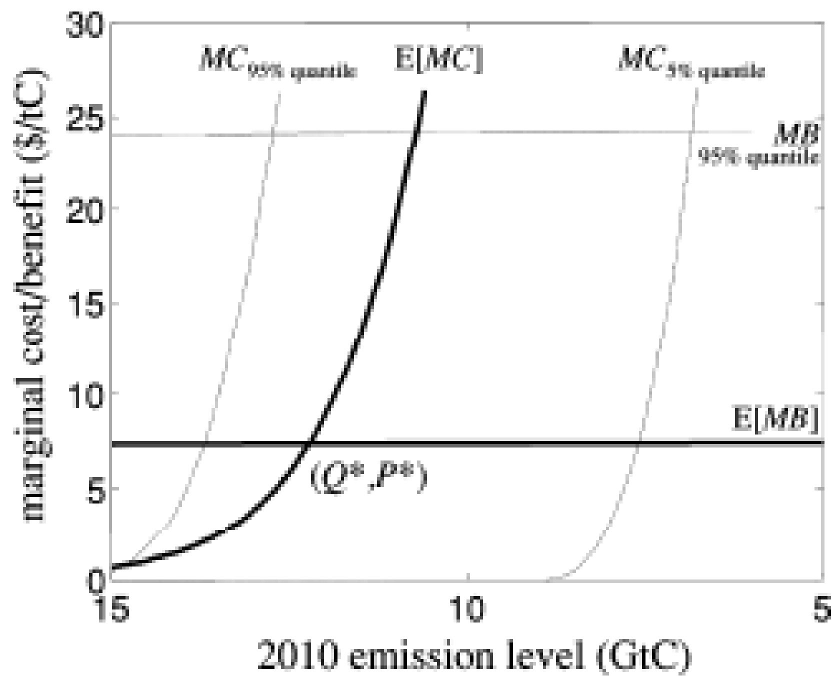


Fig. 2. Distribution of marginal costs and benefits in 2010. (The 5% quantile of marginal benefits overlaps the x-axis.)

Context

- Cap & Trade vs. Carbon Tax… Quantity vs. Price Controls
- Weitzman: Uncertainty About Costs and Benefits
- Stock Pollutant Argument
- Missing Dynamics
  - No truly complete dynamic models.
  - Either one shot uncertainty is modeled with the marginal cost and marginal benefit functions specified exogenously, or…
  - Open loop dynamic optimization is modeled, without a full dynamic equilibrium.

My Argument / Clarification

- Unspoken premise of the stock pollutant argument is that all uncertainty is short-term, transitory shocks.
  - Analogy to permanent and temporary income shocks and consumption impact.
  - Contrast pure mean reversion with pure Brownian motion.
- If any element of the shocks are permanent, there is an implicit shift in the short-term marginal benefit function.
  - A realization of a shock in one year shifts the conditional forecasts in all future years,
  - Assuming a long-term budget constraint, the marginal benefit function for this year's emissions will have shifted,
  - Cannot examine the marginal benefit function for this year's emissions locally to the current level.
- The "stock pollutant" feature of CO_2 is not dispositive in the P v. Q debate.

Continuous Time Examples

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Example Set-up

- Finite horizon date T
  - q_t -- emissions at instant t
  - Q_t -- aggregate emissions to date t
- Don't evaluate benefits…only look at the problem of minimizing the cost of achieving a given bound on emissions, Q
- $C(q_t,\theta_t) = \theta_t \exp(-q_t)$,
  - θ_t is the uncertain parameter
  - $C(0,\theta_t)=\theta_t$, i.e., there is a maximum cost
  - $\{q_t \to \infty\} \Rightarrow \{C \to 0\}$
  - no restrictions on q_t, i.e., q_t,<0 is possible, but at great cost, and Q_t>Q is possible for t<T.

Solution to the Certainty Case

- Start with the model under certainty, where θ_t grows at rate ν and assuming a discount rate, r.

- The cost minimizing emissions path has
  - …emissions growing linearly in time, so that the marginal cost grows exponentially at the discount rate, r
  - …the linear growth rate is ν-r.

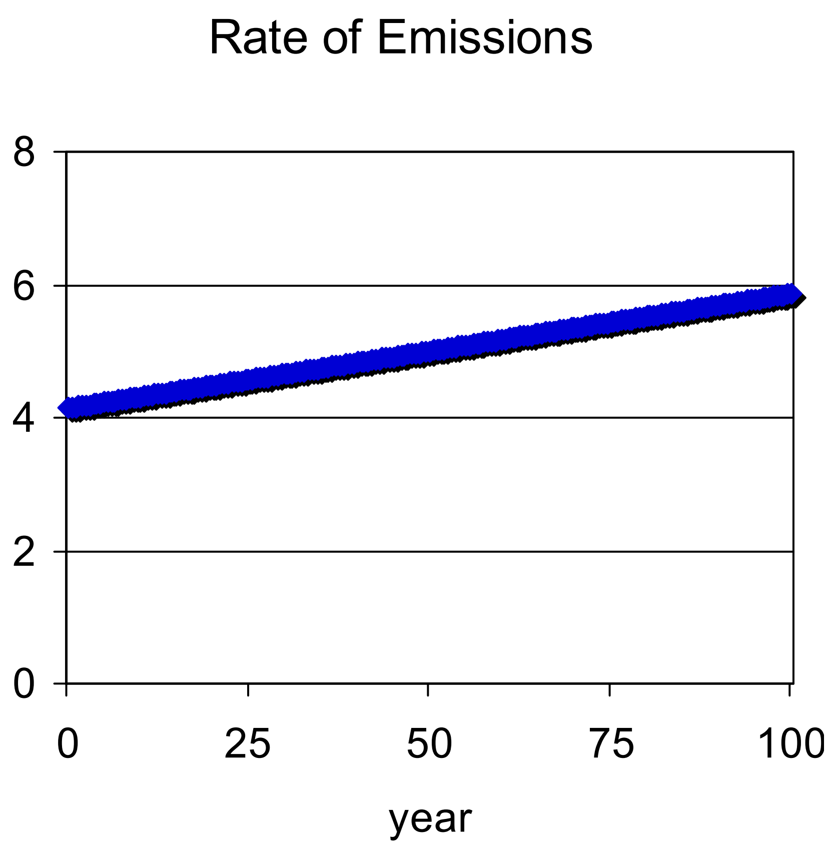
- The initial level of emissions is set so that allowed emissions are exhausted at the last instant in time

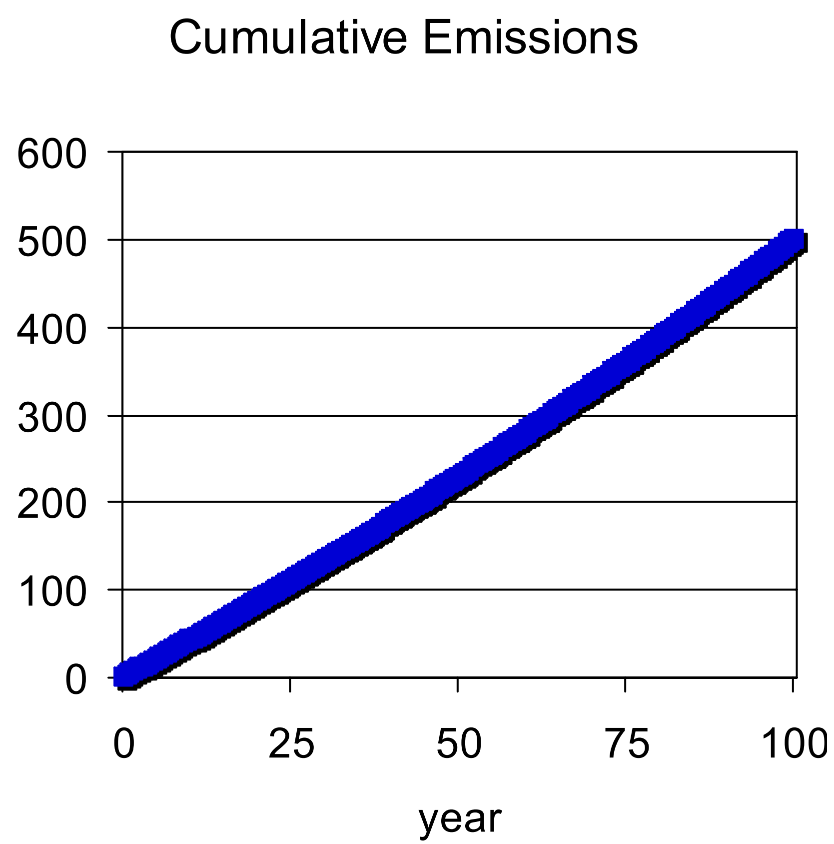
$$q_0 = Q_0/T - 0.5*(\nu-r)T$$

- Therefore, the optimal emissions path in the certainty case is

$$\begin{aligned} q_t &= q_0 + (\nu-r)\, t \\ &= Q_0/T - 0.5*(\nu-r)T + (\nu-r)\, t \end{aligned}$$

Cost Minimizing Emissions Path in the Certainty Case





What If?
Analyze off equilibrium paths in the certainty case

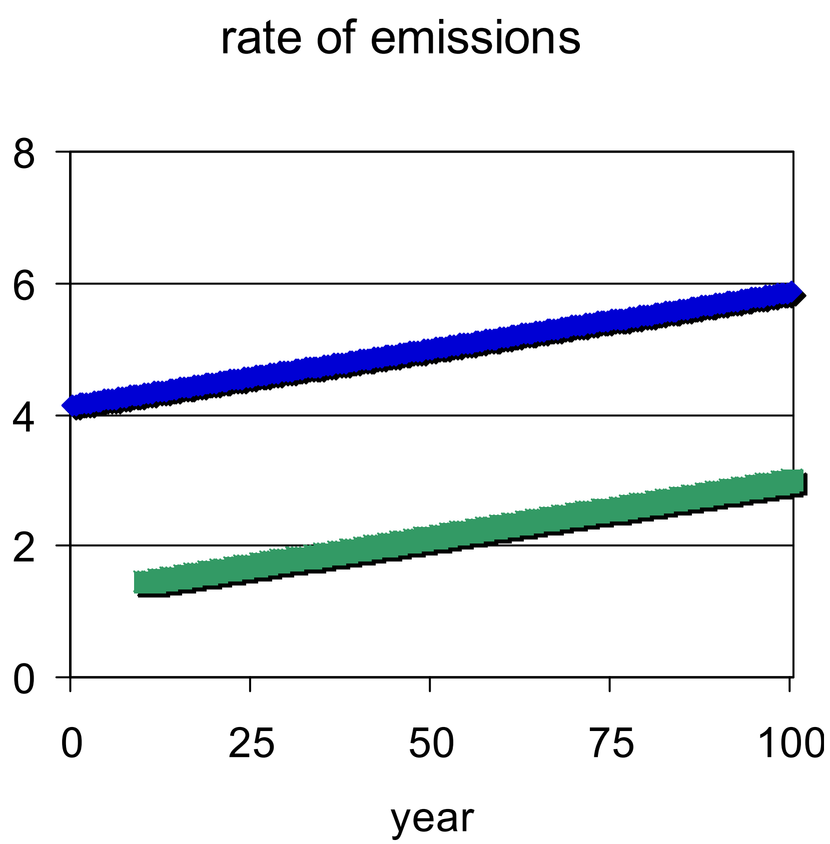
- Suppose we are at time t, and emissions to date have not followed the cost minimizing path. What is the cost minimizing path for the remaining time given the current level of aggregate emissions?
- A straightforward generalization…
- Today's cost minimizing emissions are…

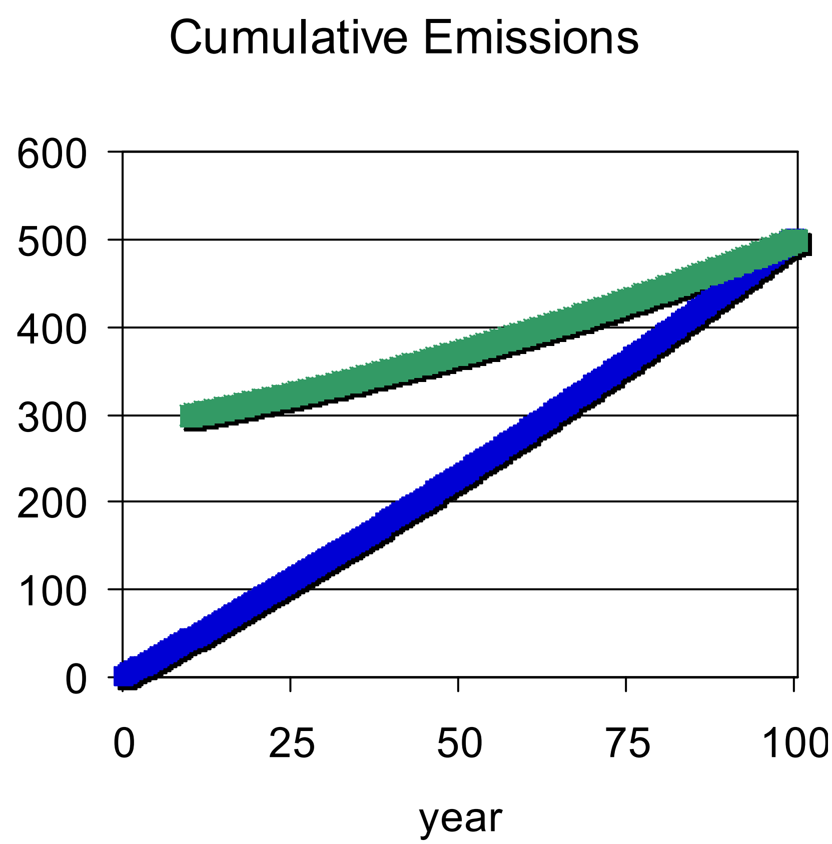
$$q_t = K(Q_t,T-t) = Q_t/(T-t) - 0.5*(\nu-r)(T-t)$$

  - i.e., as if looking forward, $\tau>t$, we hoped to follow the path…

$$q_\tau = Q_t/(T-t) - 0.5*(\nu-r)(T-t) + (\nu-r)\,\tau$$

"What If" Cost Minimizing Emissions Path Following Period of Excess Emissions



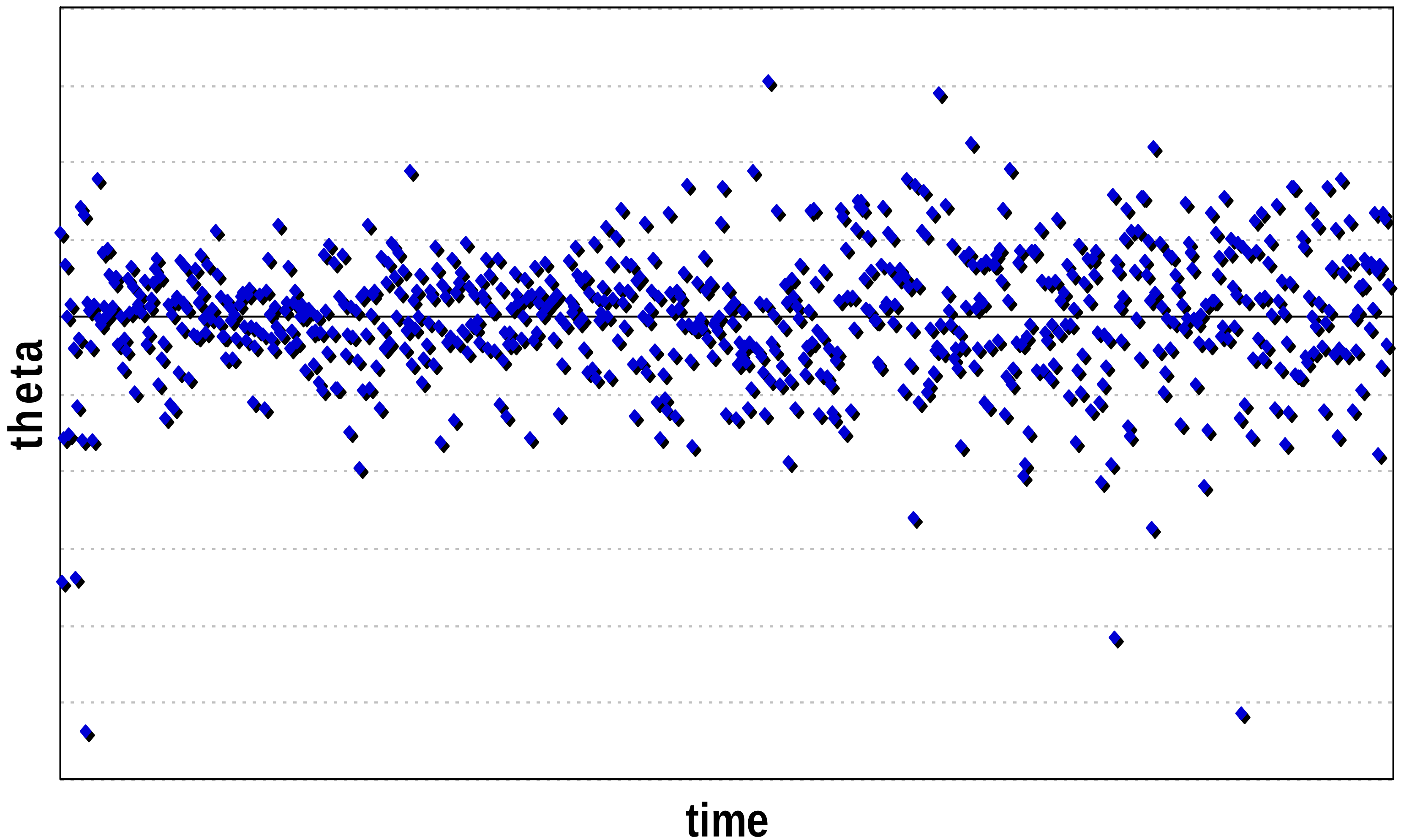


Uncertainty Dynamics

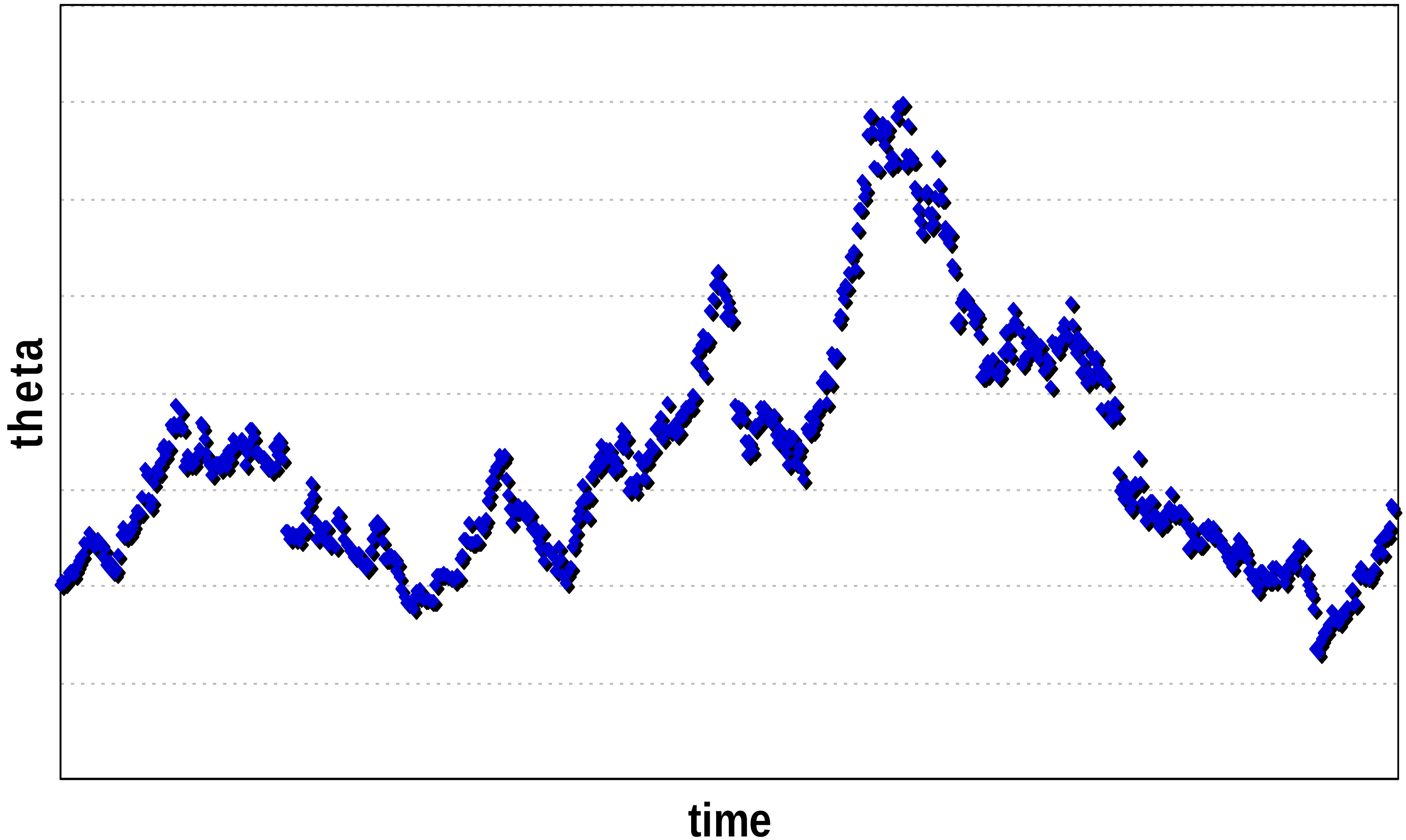
- Case 2A -- Pure Temporary Shock
  - Uncertainty is white noise: $\theta_t = \theta_0 \exp(\nu t) + \sigma\, dz$

- Case 2B -- Pure Permanent Shock
  - Uncertainty is geometric Brownian motion: $d\theta_t/\theta_t = \mu\, dt + \sigma\, dz$

White Noise: Sample Path Observed Discretely



Geometric Brownian Motion: Sample Paths Observed Discretely



Solution to Case 2A, Temporary Uncertainty

- In the face of a shock to the cost function, $dz \neq 0$, it is optimal to allow this period's emissions to adjust to the shock, completely

$$q_t^* = K(Q_t, T-t) + \sigma\, dz$$

- Variation in today's emissions, $\sigma\, dz$, is made up for by adjusting the target emission level in all subsequent periods, τ. This occurs through the adjustment of future target emissions based on aggregate emissions up to date τ, $K(Q_\tau, T-\tau)$.

- Aggregate emissions follow the process

$$dQ_t = K(Q_t, T-t) + \sigma\, dz$$

A mean reverting process, where the strength of reversion increases with the realized tightness of the cap and the shortness of time to the horizon.

Prices v. Quantities in Case C

- Instantaneously, all of the uncertainty is reflected in variation in the quantity of emissions;
- Instantaneously, there is no uncertainty about the shadow price of the optimal level of emissions;
- Price controls can always be used to implement the cost minimizing path. At each instant a price can be fixed based on cumulative emissions to date, without regard to the realization of the cost parameter, and the quantity can be allowed to be set optimally against this price given knowledge about the realized cost parameter:

$$P_t = E[q_t] \exp(-K_t(Q_t)) \neq q_t \exp(-q_t)$$

- Note, however, that the price level must be regularly updated, and indeed must be used to help make up for earlier "excess" emissions.
- Strict quantity controls can never implement the cost minimizing path since output in each instant of time needs to be responsive to the current realization of the shock.

Solution to Case 2B, Permanent Uncertainty

- The emissions path remains as in the certainty case,

$$q_t^* = K(Q_t, T\text{-}t)$$

- At any given instant, in the face of a shock to the cost function, $dz \neq 0$, it is *NOT* optimal to allow this period's emissions to adjust to the shock *at all*.
- Aggregate emissions follow a fixed, deterministic path, independent of the sequence of shocks
- Marginal cost varies, instant by instant, reflecting the evolution of the uncertain cost parameter, θ_t. Marginal cost follows a geometric Brownian motion.

Prices v. Quantities in Case D

- Price controls do not implement the cost minimizing path.
- Quantity controls, specified period-by-period, can be used to implement the cost minimizing path.
- Note this does not speak to the optimal path, since we have not addressed the weighing of costs and benefits.

Mapping the Prices v. Quantities Debate onto the Tax v. Cap Policy Space

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Dynamic Models & the Rate of Information Flow

- The issue at hand is an assumed regulatory delay… controls are specified, uncertain variables are realized, private actors observe them while public actors don't, and actions are taken based on controls specified ex ante.
- Obviously, in the context of a dynamic model, with repeat performance, the question arises, how long is the regulatory delay? How long before the regulator eventually observes the cost parameter and can re-adjust the control parameter?
- This question is especially relevant when debating the stock pollutant argument, since the time frame is many decades long. Regulations will be adjusted. Much interim cost information will be observed along the way.
- The existing models have never raised this question, at all.

Cap & Trade & Banking and Borrowing

- As debated in the theoretical economics literature, quantity controls are always period-by-period controls.
- The discussion focuses on annual time frames and poses a fixed annual cap on carbon emissions against a fixed annual tax on carbon.
- But actual carbon cap&trade proposals allow banking of allowances across years.
- Cap & trade with frictionless banking and borrowing of allowances through time implements the cost minimizing emissions path in *BOTH* case 2A and 2B type uncertainty.
- The economists' comparison of PvQ controls and Cap v. Tax policy sets up a straw man debate that is not relevant to the actual policy choices.
- The real question is a lower order issue of how frictionless across years are emissions markets, and what institutional features need to be redesigned to improve the effectiveness of banking and borrowing.

Cap & Trade & Banking and Borrowing (cont.)

- Tax advocates assert that existing emissions market prices exhibit "too much" volatility. A tax can be readily fixed to a constant number.
- This assumes all uncertainty is like Case 2A.
- In Case 2B, the right shadow price does exhibit volatility. A fixed tax would not be the optimum.
- Of course the question of "too much" volatility is a question of whether the observed volatility is reflecting institutional frictions and other problems, or reflecting the fundamentals.

CO2 Market Design

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Current Debates in the US

- Cap&Trade v. Tax v. Safety Valve v. Carbon Market Board
  - Then there is always Command & Control as well as Technology Policy
- Fears…
  - too much volatility,
  - that the price will be higher than expected,
  - markets don't work,
  - financial institutions are purely parasitic.

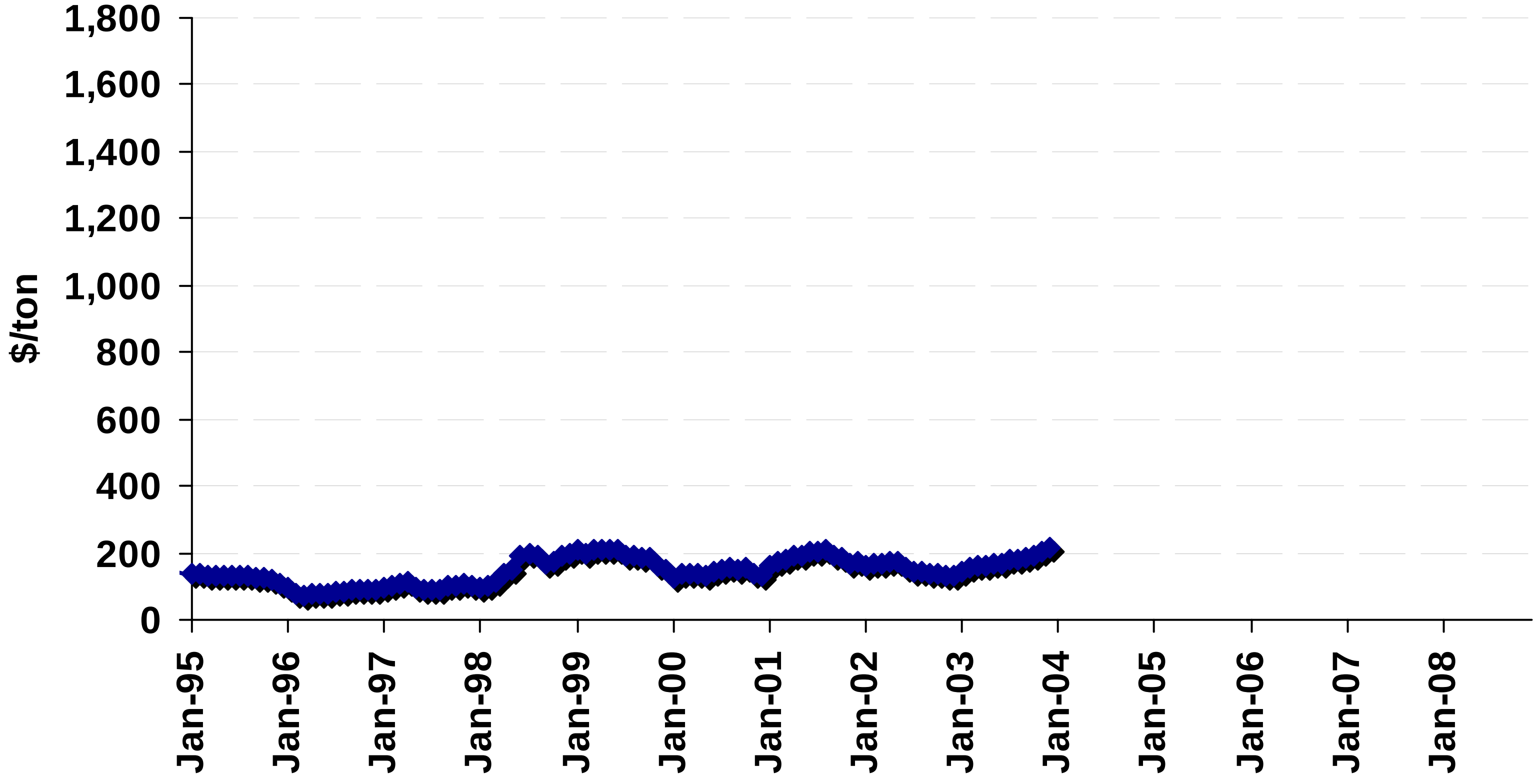
Lessons from the EU-ETS?

Lessons from the EU-ETS?

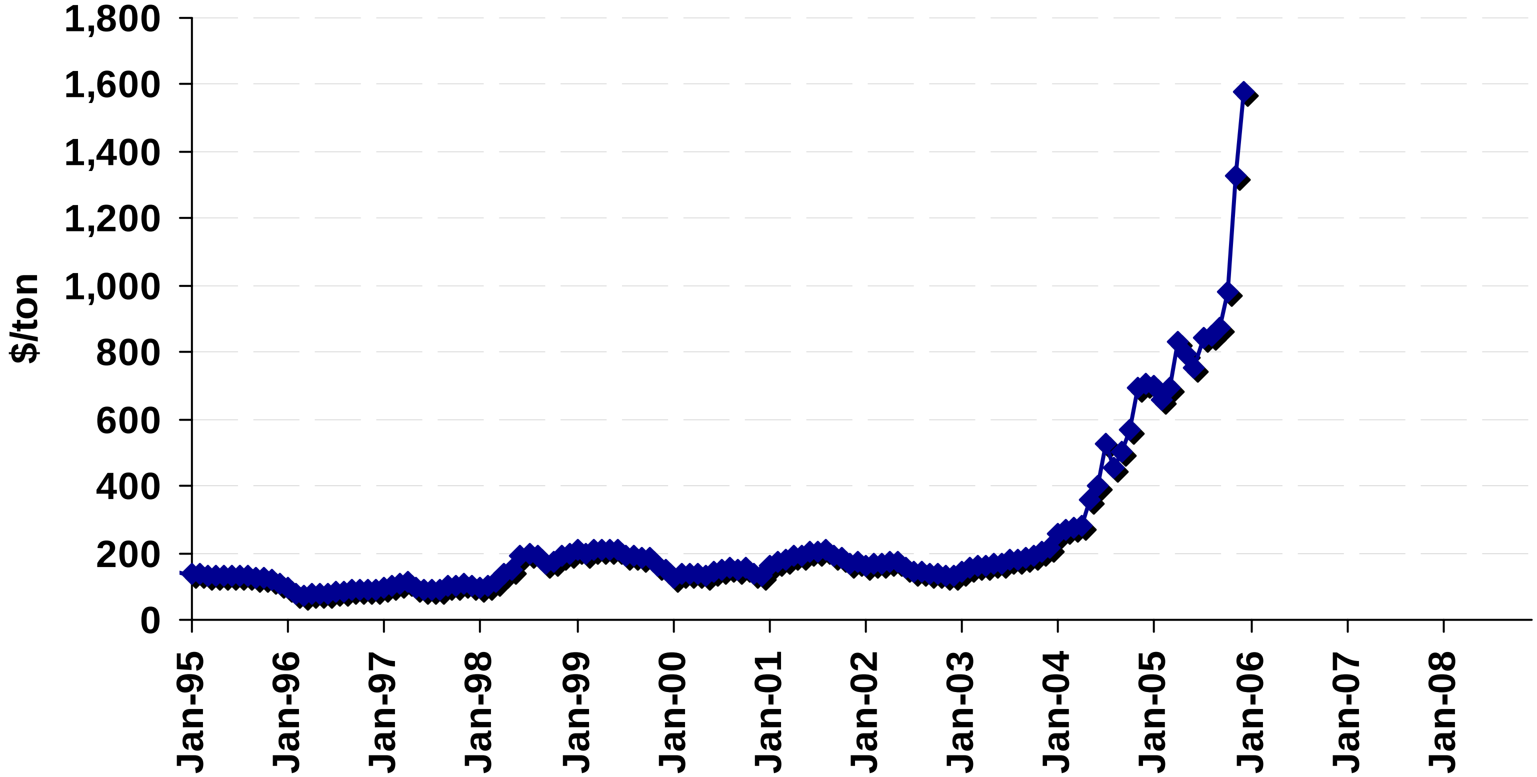
- Start-up phase was illiquid and out-of-balance
  - Power sector was purposefully made short,
  - Small industrials were made long,
  - Differences in familiarity with the market meant that the longs weren't present initially.
  - Points to a complicated problem in allocations. The tendency to try to allocate to the natural short reflects an implicit distrust in trading that can be self-fulfilling.
- Procedures for information flow had not been worked out, leading to the price drop of April '06.
- End of '07 price illustrates why banking should be unfettered.

Lessons from the US SO2 Market?

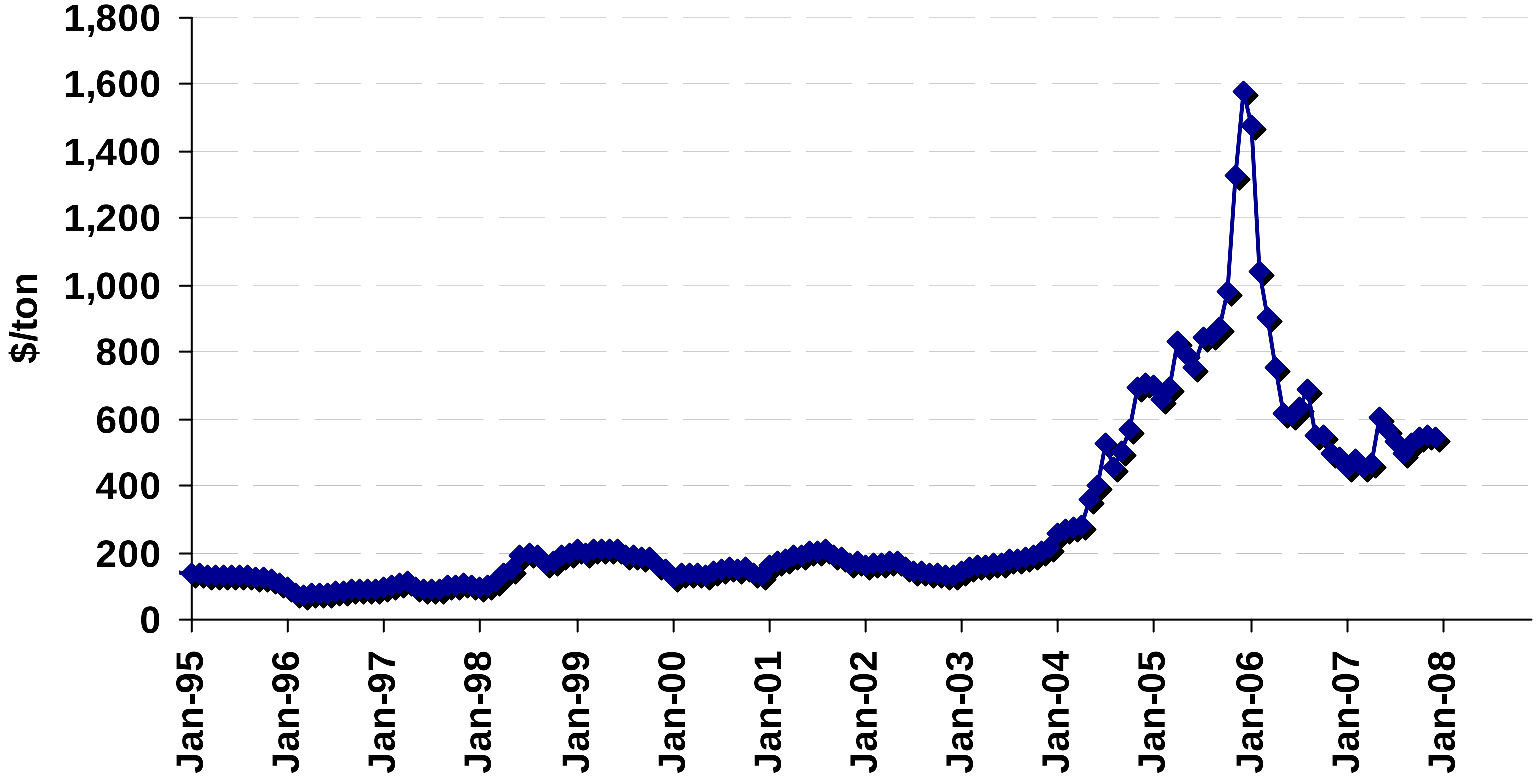
Lessons from the US SO2 Market?



The ’05-’06 SO2 Price Spike

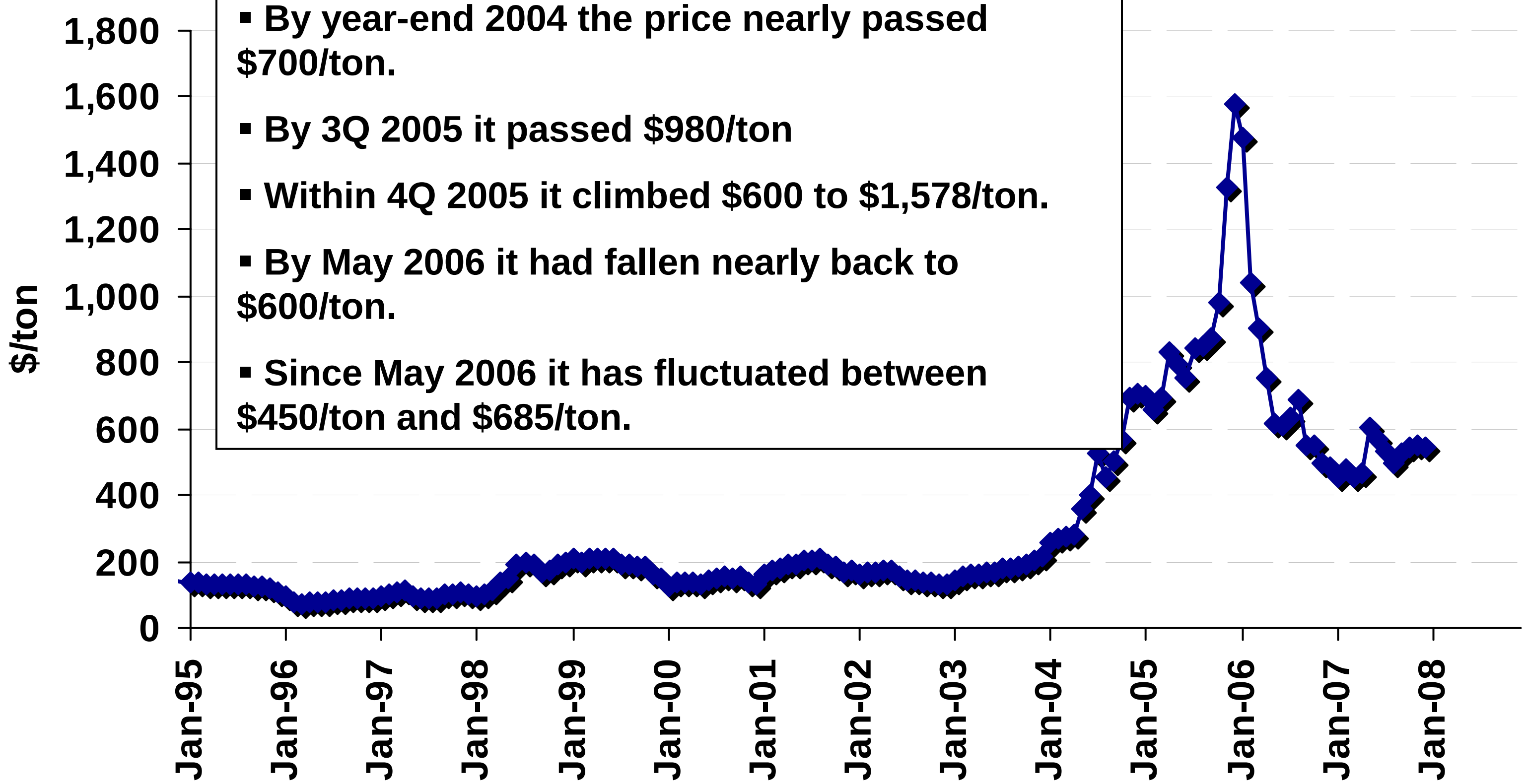


The '05-'06 SO2 Price Spike



The ’05-’06 SO2 Price Spike

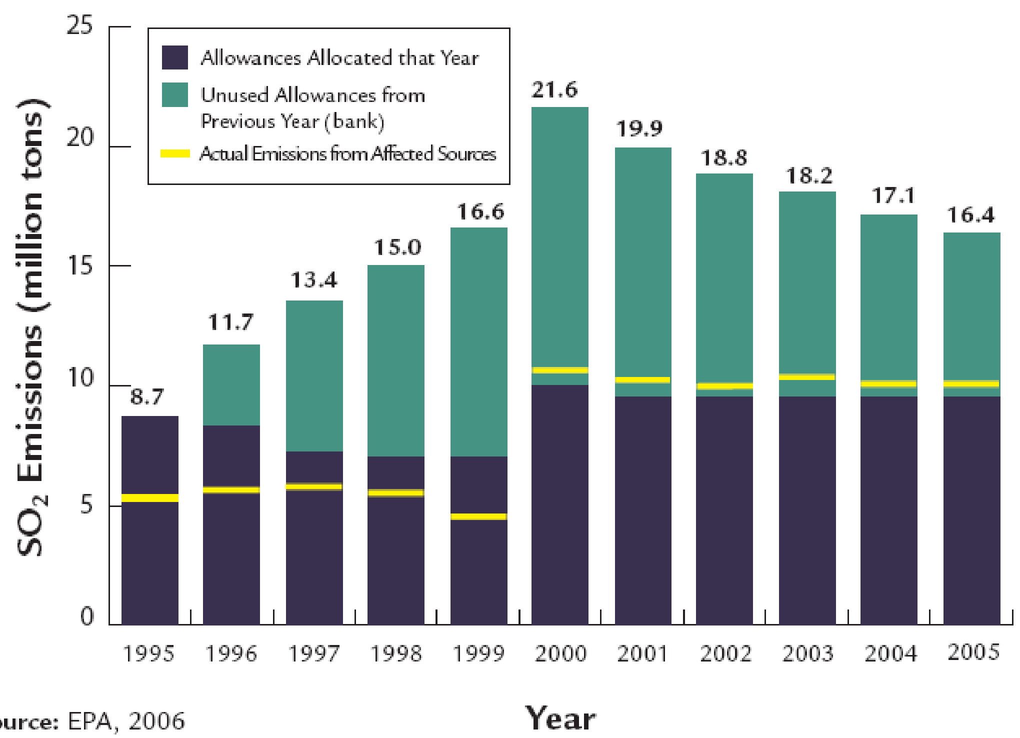
- Through year-end 2003 the price ranged within a band from $69/ton to $217/ton.
- By year-end 2004 the price nearly passed $700/ton.
- By 3Q 2005 it passed $980/ton
- Within 4Q 2005 it climbed $600 to $1,578/ton.
- By May 2006 it had fallen nearly back to $600/ton.
- Since May 2006 it has fluctuated between $450/ton and $685/ton.



Banked allowances should smooth the impact of transitory shocks.

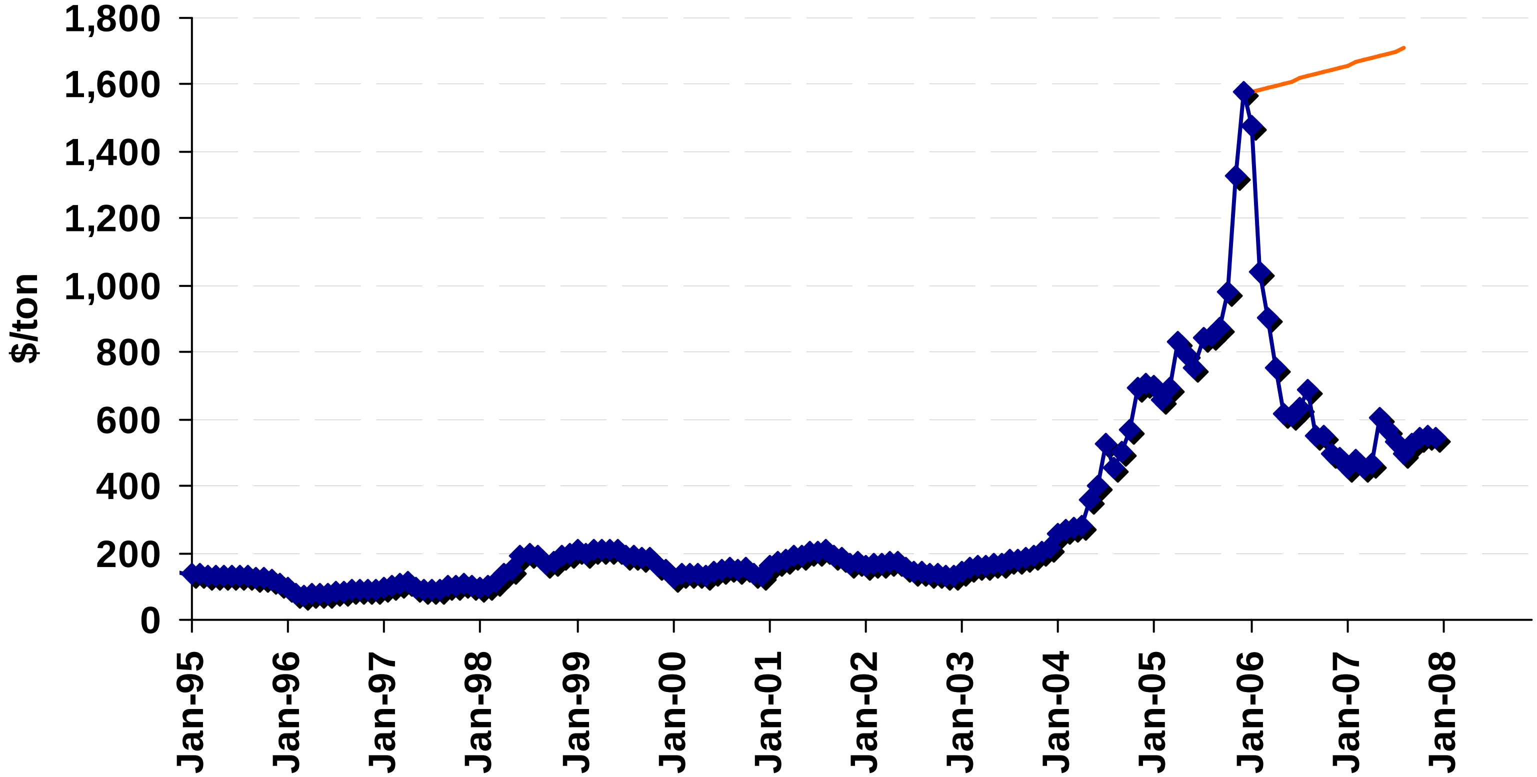
- SO_2 allowances are dated or vintages, but are usable to cover emissions in any year after their allocation.
- A large bank existed…

Figure 3: SO_2 Emissions and the Allowance Bank, 1995-2005



Source: EPA, 2006

Forecasted price @ Dec '05 given a bank.



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Does this matter?

- What was the added cost of compliance due to the spike?
- During the “inflation”, between September 2004 and April 2006…
  - there were more than 11 million allowances sold between economically distinct entities as recorded at the EPA registry—compared against approx. 10 million tons in emissions,
  - at a weighted average inflation of $449/ton,
  - implying a potential $5 billion in extra costs to those buying allowances at the inflated price.

- Lessons for the design of a US CO_2 market.
  - …and worries about the debate.

Fundamental Explanations

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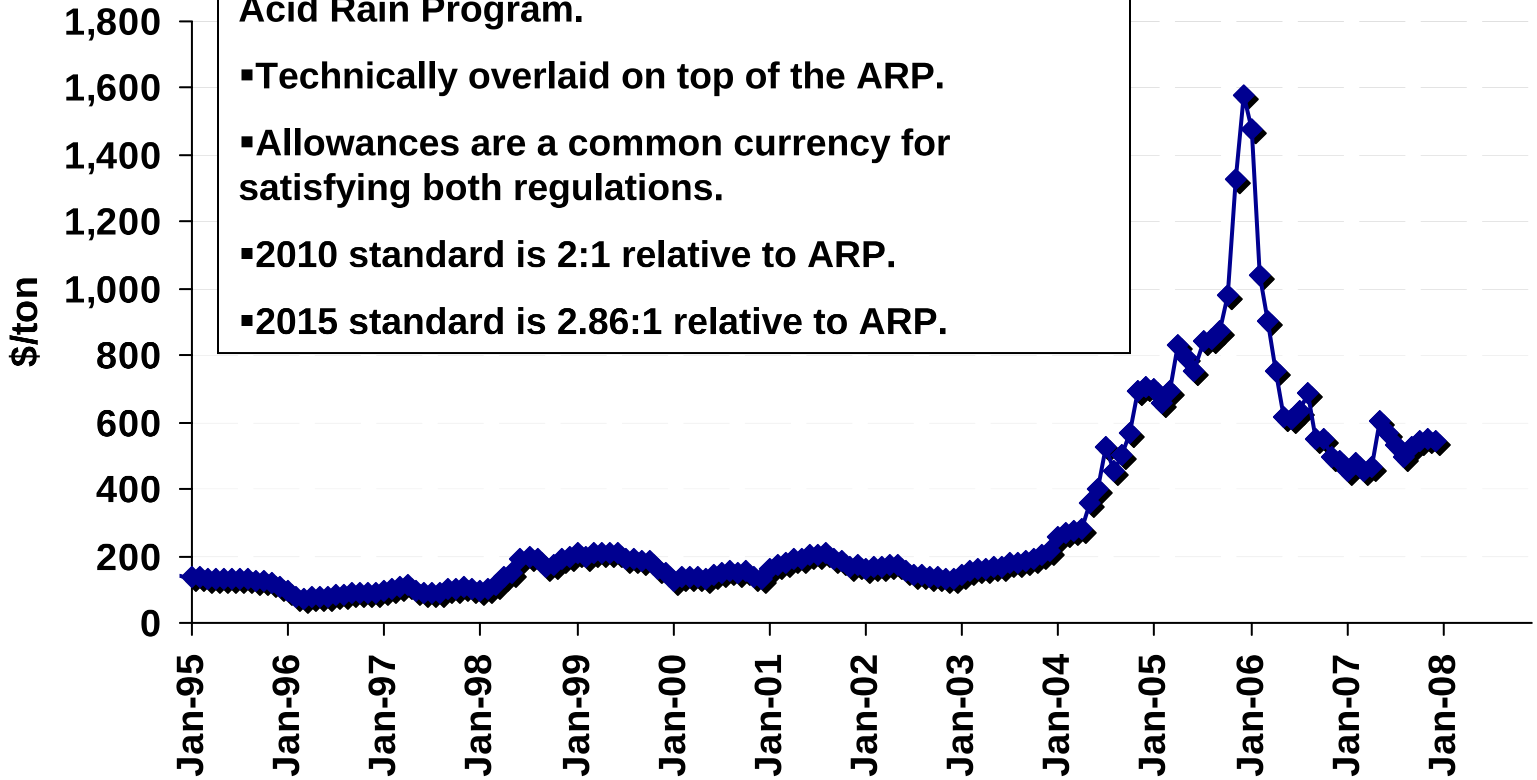
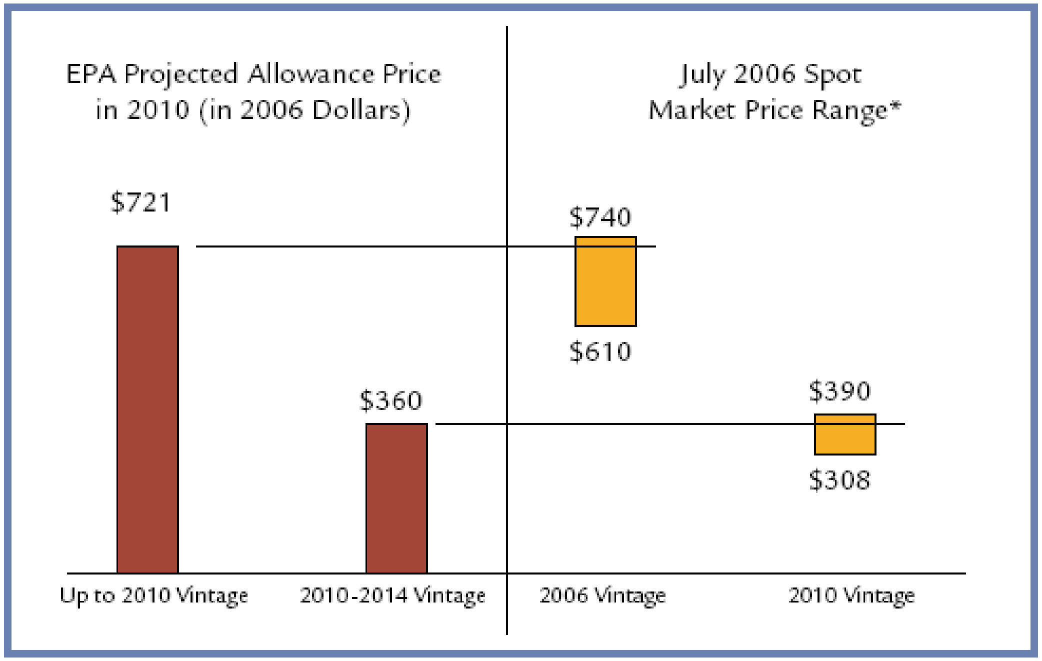
The Clean Air Interstate Rule

- **Finalized in March 2005.**
- **Imposes an SO2 cap tighter than the original Acid Rain Program.**
- **Technically overlaid on top of the ARP.**
- **Allowances are a common currency for satisfying both regulations.**
- **2010 standard is 2:1 relative to ARP.**
- **2015 standard is 2.86:1 relative to ARP.**



Forecasted higher compliance costs and allowance prices.

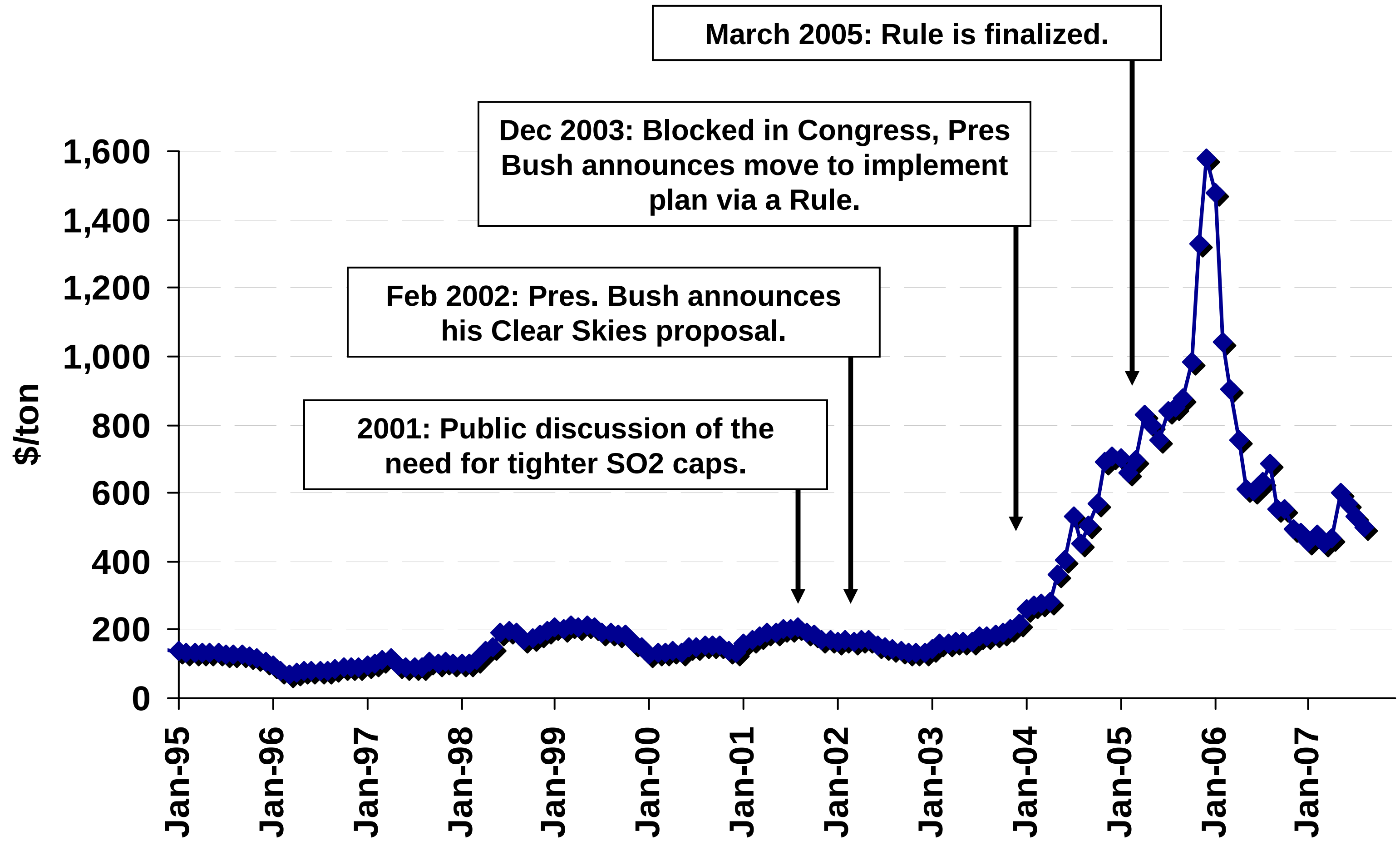
Figure 6: Actual and Forecast Allowance Prices



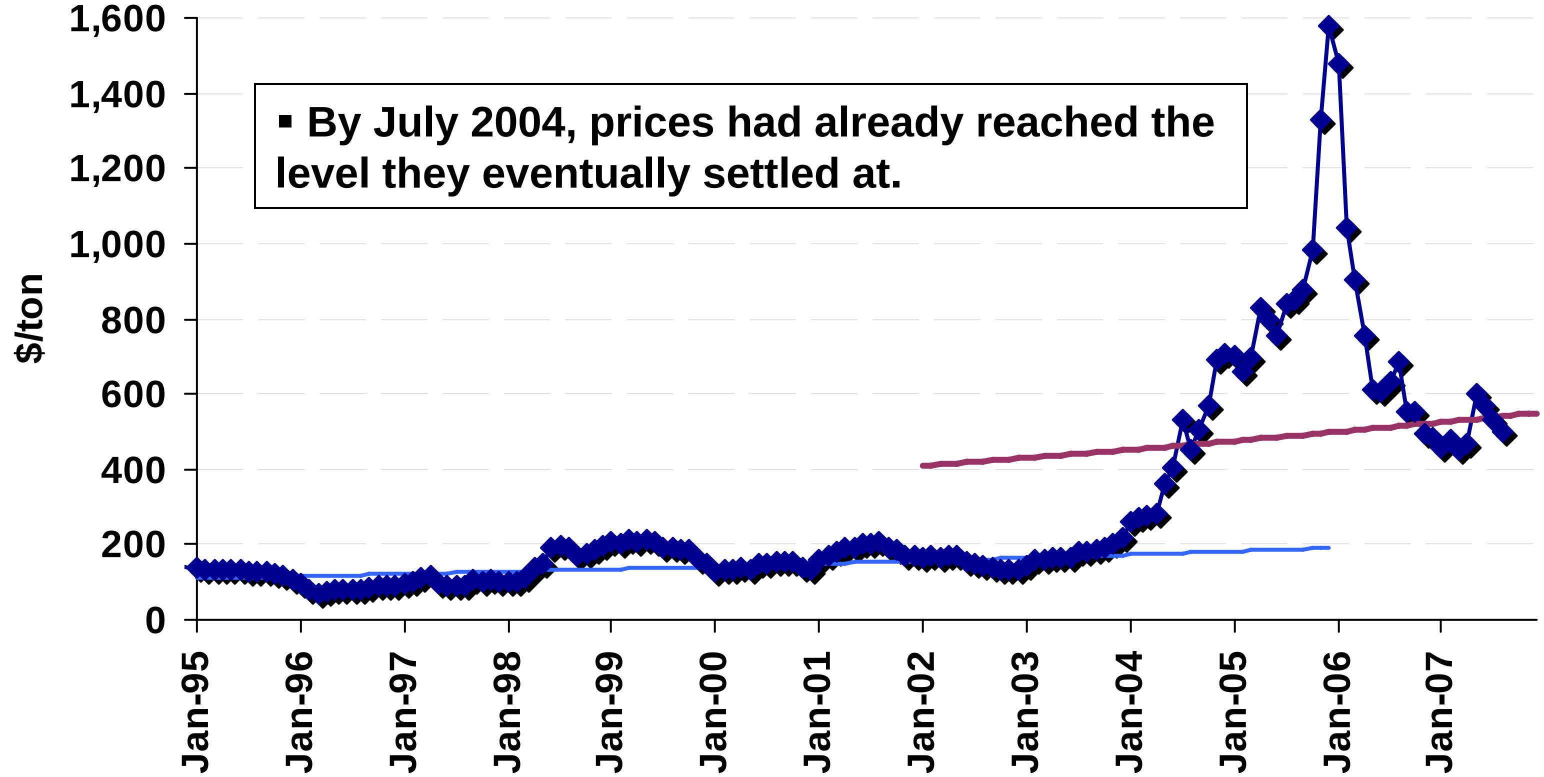
* EPA analysis suggests that 2006 vintage allowances should be selling for about $600 per allowance and 2010 allowances should be about $300 per allowance.

Source: EPA, 2006, and Evolution Markets, LLC, 2006

Key Events Leading to CAIR



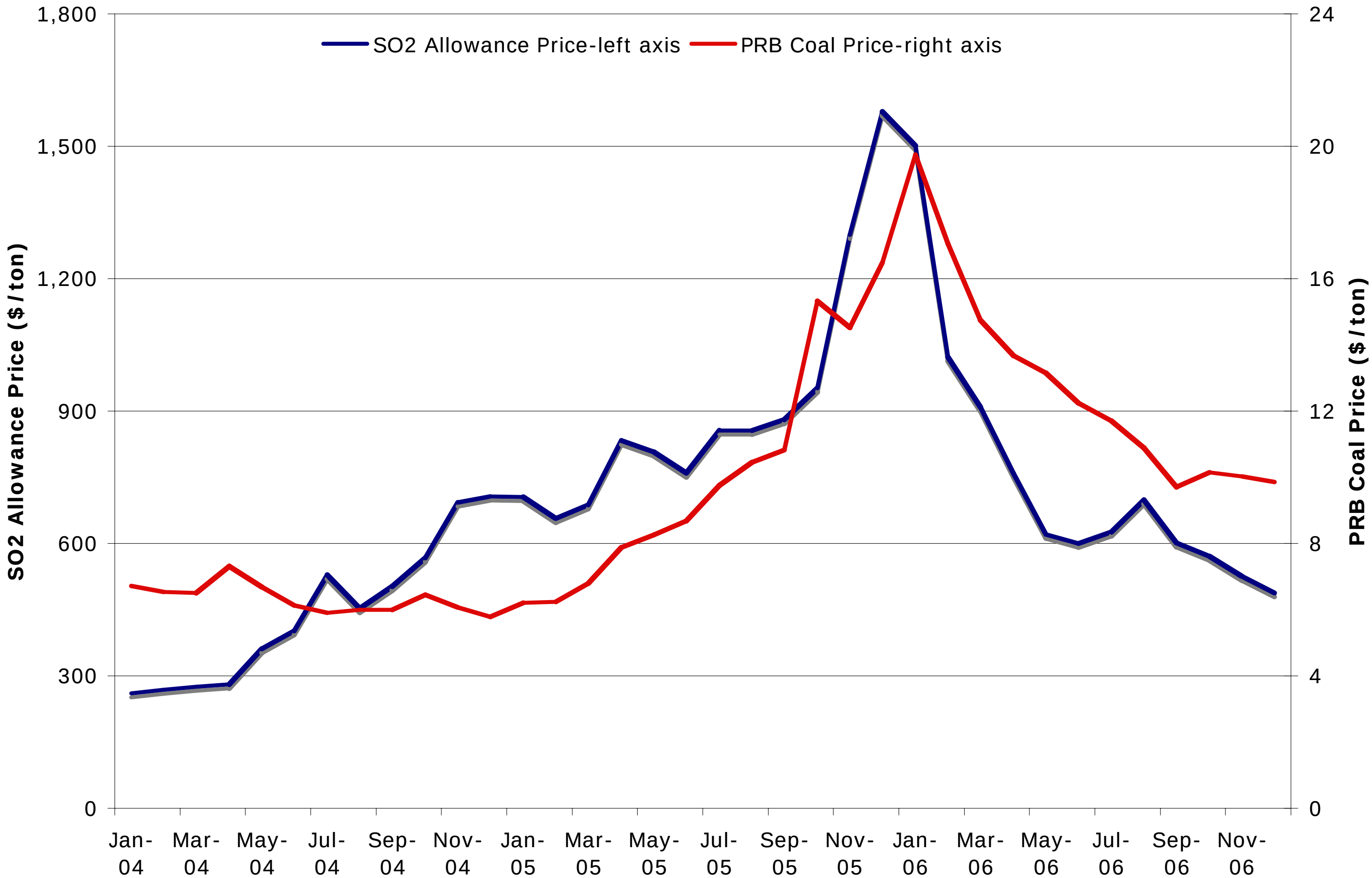
Anticipation and the SO2 Price.



Supply disruptions to PRB coal

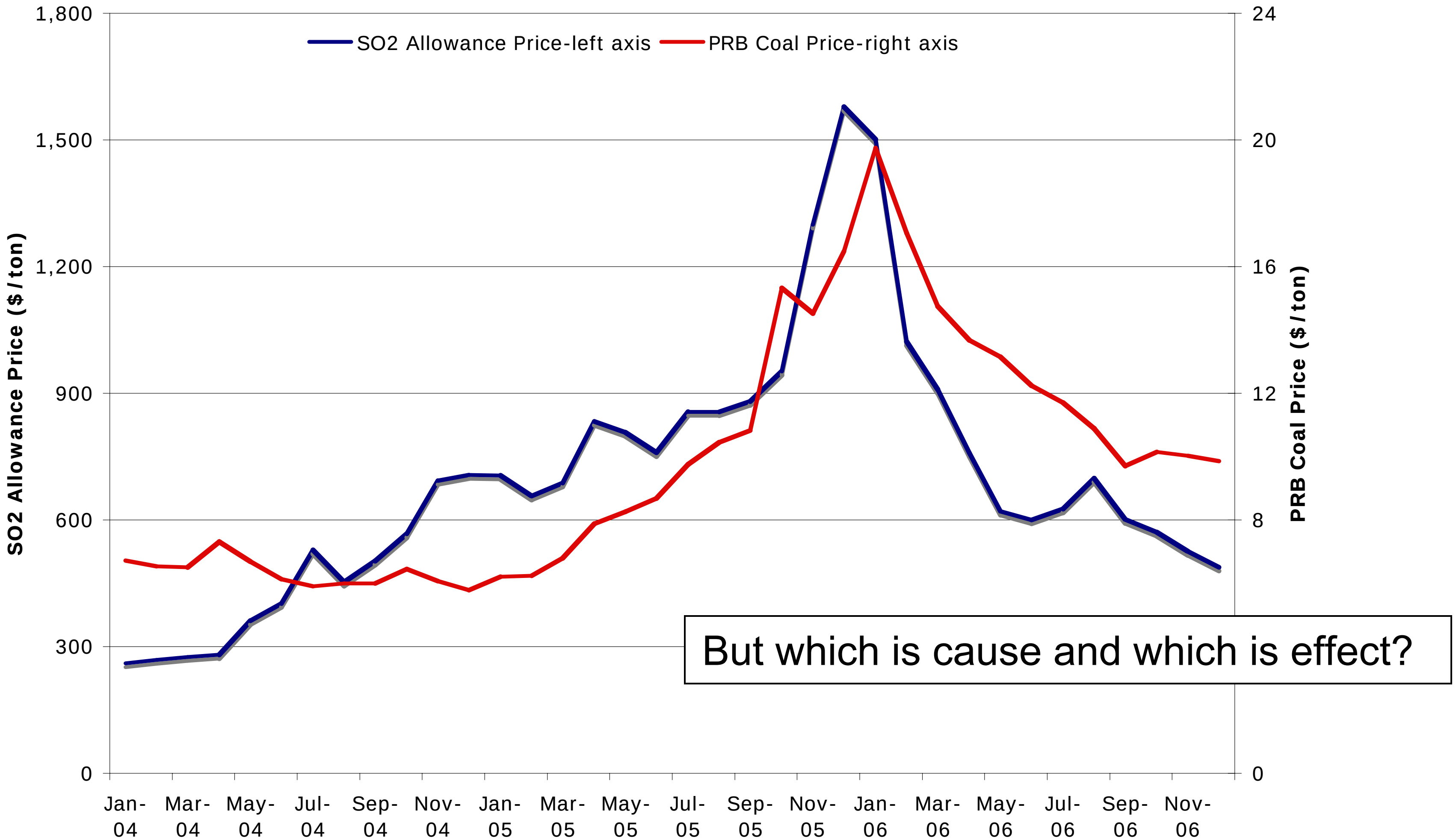
- A track failure and derailment in Wyoming in May 2005 caused extensive rebuilding programs by the two main operators, Union Pacific and Burlington Northern Santa Fe. The railroads cut contracted deliveries by 15-20% through November.
- October rains also damaged Union Pacific track near Topeka, disrupting deliveries further.
- Arch extended the outage on its West Elk mine, yielding estimated losses of 1.1 million tons. CONSOL Energy reported delays in repairing its Buchanan mine.
- The affected utilities switched dispatch to gas (Xcel, Arkansas Electric) or purchased power on the open market (Xcel, WE Energies, Entergy & Alliant Energy), shifted to using high sulfur coal (AEP) or imported coal (CPS).
- Coal's share of electric generation in 2006 was 0.6 percentage points less than 2004. Total generation was up 2.4% to 3.9 million killiowatts.
- PRB spot coal prices were up 220% in Dec 2005 over Dec 2004, reaching $18.25/ton.

Price correlation between PRB and SO2.



Source: Platts weekly PRB coal prices averaged monthly; Cantor Fitzgerald monthly SO2 index

Price correlation between PRB and SO2.



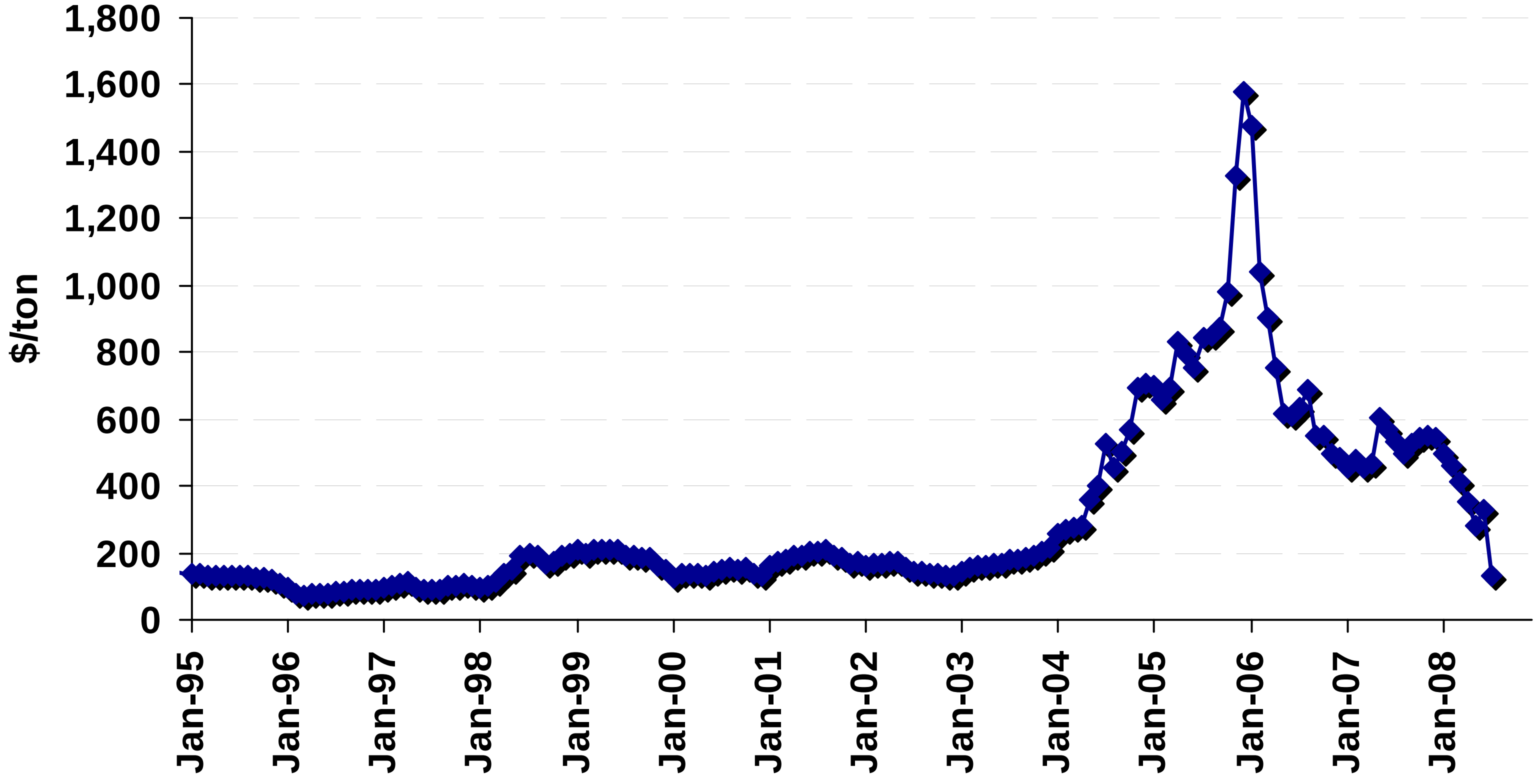
Source: Platts weekly PRB coal prices averaged monthly; Cantor Fitzgerald monthly SO2 index

How correlated should allowance prices be to transitory shocks?

- Received wisdom has been that the daily CO2 price variations in the EU-ETS are driven by variations in natural gas prices and weather variables.
- Given a sufficient window for banking & borrowing, these variables should be mostly transitory.
- The EU-ETS trial period was only 3 years, so a transitory variable becomes, in part, permanent.
- How long is long enough?

CAIR Epilogue

- July 08: DC Court of Appeals invalidates CAIR completely.



An Alternative Explanation: Market Design

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Float / Liquidity / Squeeze

- Float: portion of total asset pool available for trade.
  - In stocks, it is the number of outstanding shares, minus restricted shares, possibly minus unrestricted shares held by key blockholders.
  - Key concept for theories of the internet stock bubble & crash.
    - Many internet stocks initially floated a very small fraction of total shares; vast majority of holdings were restricted.
    - Also a small supply of shares for shorting.
    - Therefore the price does not reflect the "market" perception of value.
    - Crash follows the release of a mass of unrestricted shares onto the market.
- Liquidity is a slightly different concept.
  - A small float is likely to lead to low liquidity. Raises search costs.
  - But not necessarily: internet stocks were very liquid.
- Squeeze arises when some parties have a need to obtain the asset within a short period of time.
  - Illiquidity increases the likelihood of a squeeze developing.
  - Primarily associated with futures contracts and designated delivery types and locations.

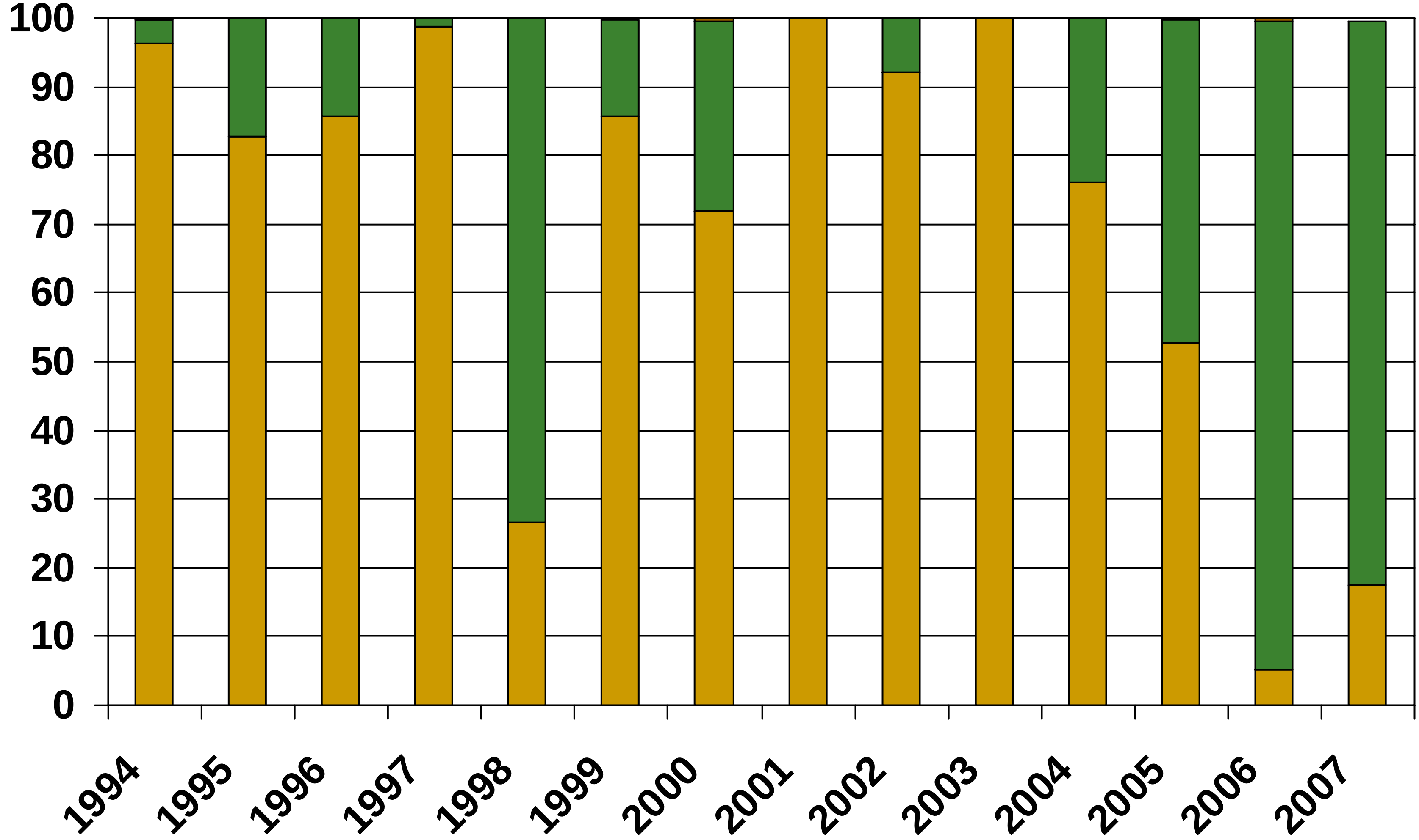
Float in the SO2 market

- Allocations to shorts is the first problem.
  - Allocating the allowances to “shorts” reduces the parties looking to trade, thins the market.
- Free allocations is the second problem.
  - Asset is held on the books at a zero tax basis; i.e., value or “income” has been received, but not recognized on the accounting statement.
  - When the allowance is used, the value is realized, but only at the same time as the realization of a liability, the need to emit.
  - Suppose the current market price of the allowances increases above the “fundamental” value. Suppose further that we can confidently predict the price will deflate again to its fundamental value. An allowance holder who is “banking” that allowance should sell the asset, planning to repurchase at a later date when the price has returned to fundamentals.
  - Realizes a taxable gain today equal to (i) the difference between the market price and the fundamental value, plus (ii) the market price less the zero basis. This accelerates the tax paid on the freely allocated allowance. The future need to emit is a liability that will be realized in the form of the repurchase of the allowance at the then prevailing market price.
  - Speculative gain from arbitrage is hit by an extra tax burden in the form of acceleration of tax.
- Allocations to regulated entities is the third problem.
  - Zero incentive to maximize the value of their bank via speculative trading.

Float in the SO_2 market (cont.)

- Fundamentals explanations interact with the problems of float.
  - CAIR causes a sudden decrease of banked allowances available for trade.
  - PRB disruptions creates specific utilities with an immediate demand to cover: Allegheny.
- Other factors.
  - SO_2 futures markets are being created.
    - December 04, the Chicago Climate Exchange announces plans to begin futures trading in SO_2.
    - February 05, the NYMEX Board approves plans to begin futures trading in SO_2.
    - Suppliers of liquidity to these markets require an inventory of allowances to do their business.
  - Commodity funds look to environmental markets.

Percent of Auctioned Allowances Sold to Financials



The End

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