Greening the Economy with New Markets:

System Dynamics Simulations of Energy and Environmental Markets

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Abstract

The paper draws lessons from previous applications of system dynamics to newly created markets dealing with energy and the environment. The examples include markets for renewable certificates and wholesale electricity generation. The previous studies show that system dynamics studies stand alone in aiding our understanding of the volatility that could be expected from newly created markets.

The biggest environmental challenge of our century is the excessive accumulation of greenhouse gases in the atmosphere and the threat of rapid climate change. Substantial reductions in carbon dioxide (CO2) emissions are required if the world is to avoid dangerous anthropogenic interference with the climate system. Countries around the world are experimenting with a combination of green stimulus spending, regulations and market incentives to reduce their CO2 emissions. This paper focuses on the design of carbon markets to put a price on the emissions. The paper reviews the recent proposals in the USA and their unfortunate tendency to rely on massive use of offsets. The paper concludes with a discussion and simulation of Cap and Dividend, a dramatic new proposal to lower emissions in the USA.

Introduction

The theme of the 2010 conference is *Greening Society, the Economy and the Future*. The theme reflects global concerns about environmental and economic issues. An important policy option for dealing with environmental and economic challenges is green stimulus spending. The news headlines in early 2010 are filled with announcements of government programs to create new jobs and to spur economic growth, especially growth in recycling, carbon reduction, energy conservation, river management and protection of natural resources. "Green New Deal" spending in South Korea (our host country) is expected to be $38 billion. Appendix A describes the plans and rational for green stimulus spending.

Regulations are a second major policy option to deal with the environmental challenges of our time. An important federal regulation in the USA is the Corporate Average Fuel Efficiency (CAFE) requirement on the companies that manufacture vehicles.[1] State standards are also an important part of the regulatory rules in the USA. One example is state enacted Renewable Portfolio Standards (RPS) which call for a growing fraction of electricity generation to come from renewable sources. Another important regulation calls for new power plants to limit CO2 emissions.[2]

Incentives are the third major policy choice for governments around the world, and most countries will use a combination of green stimulus spending, regulations and incentives to green their economies. Incentives can be specified administratively, or they can be designed to emerge from newly created markets. System dynamics has been put to good use to help policy-makers anticipate the dynamics of new created environmental and energy markets. Appendix B summarizes the findings from a study of Tradeable Green Certificates (TGCs), a market-based incentive to encourage electricity generation from wind and other renewable sources. The TGC study revealed an inherent tendency for the new market to deliver volatile prices, even under highly controlled conditions. The TGC study reinforced the arguments of countries that support investment in renewable generation through administrative incentives.[3]

Similar results were obtained in a system dynamics study of newly created markets for wholesale electricity in California. The model was developed for western power agencies concerned about construction of new power plants and the possibility for highly volatile prices. Appendix C describes the "California electricity crisis" study. It revealed the underlying tendency for construction to appear in waves of boom and bust. We found that wholesale energy prices would not motivate a timely and stable pattern of power plant construction, and we

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[1] The CAFE goal from legislation in the 1970s called for the fleet average efficiency to reach 27.5 miles/gallon by the year 1985. In 2008, Congress extended the standard to 35 miles per gallon.

[2] The standard was adopted in California, Oregon and Washington. It limits emissions from new power plants to the emissions from a highly efficient, combined-cycle power plant fueled by natural gas. The new standard would prohibit the construction of new coal-fired power plants that are either located in the three states or serving loads in the three states.

[3] The most common administrative incentive is the fixed, feed-in tariff (which calls for the distribution company to pay a specified price for renewable generation). In the USA, the administrative incentive takes the form of a production tax credit for renewable generation.

recommended that a fixed capacity payment be used to supplement the price signal from the wholesale energy market.

The main lesson from the previous studies is that system dynamics provides a unique ability to help us understand the underlying reasons for volatility in newly created markets. Both the TGC study and the California electricity crisis study stood alone in their simulation of the price volatility. And both studies demonstrated a need for administratively specified incentives to avoid highly volatile behavior from newly created markets. These lessons teach us to be alert for similar findings in the study of newly proposed carbon markets in the USA.

Carbon Markets in the USA

Some background on carbon market proposals is given in Appendix D and E. Appendix D describes the Climate Stewardship Act of 2003, the first serious carbon policy proposal in the USA. Appendix E describes the market proposals over the past seven years. The encouraging trend is the imposition caps on emissions that stretch further into the future and which call for deeper cuts in emissions. However, there are discouraging trends in the cap and trade proposals, especially the growing dependence on offsets to comply with the cap on emissions. I believe that the best of the proposed carbon markets is the cap and dividend proposal by Senators Cantwell (D, Washington) and Collins (R, Maine).

Cap and Dividend: The CLEAR Act

This paper focuses on the CLEAR Act by Senators Cantwell and Collins. CLEAR is short for the Carbon Limits and Energy for America's Renewal. It calls for the imposition of a scientifically based cap on CO2 emissions. The cap would apply to the upstream companies that produce or import fossil fuels. The higher prices of fossil fuels would then work their way through the US energy system, sending improved signals to all businesses on the value of avoiding CO2 emissions.

The CLEAR Act differs in several fundamental respects from the more common cap and trade proposals which call for a large fraction of the allowances to be issued at no cost to various energy companies. (Such proposals are sometimes criticized as "cap and give away" proposals.) Issuing free allowances can lead to wind-fall profits or to reduced price signals from those companies whose retail rates are subject to rate-of-return regulation. Giving away allowances inevitably involves "picking favorites" since policy makers must pick and chose which industries will receive larger shares of the free allowances. The CLEAR act avoids this problem by requiring all of the allowances to be purchased at auction, an approach that receives nearly unanimous approval from economists. The upstream energy companies would purchase allowances at auction and comply with the cap without the use of offsets. The restriction against offsets removes the ambiguities and difficulties associated with establishing a credible market for contracts with unregulated companies.

The CLEAR Act calls for 75% of the auction revenues to be returned to consumers on an equal, per capita basis. The average household is estimated to receive an annual refund of $1,000. (This is the *dividend* in cap and dividend.) The dividend is estimated to offset energy price increases that most consumers would experience at the retail level (Boyce 2007). The political appeal of the CLEAR Act is the imposition of a scientifically based cap while using the dividend to keep the majority of low to middle income families whole. The economic appeal is an undiluted price signal that works its way through the entire energy system. The other 25% of the auction revenues would go into a Clean Energy Reinvestment Trust Fund (CERT). The CERT funds could be used for a wide variety of purposes including projects to assist some regions to deal with climate change adaptation and to help other regions make economic adjustments to the changes in the energy system.

The CLEAR Act proposes both a price ceiling and a price floor, often called a "price collar." The proposed collar is plus-or-minus 50% of a reference price with the goal of limiting[4] price volatility for consumers, fuel producers and investors in new energy technologies. The price ceiling would be enforced with sale of the extra allowances beyond the specified cap. The revenues from the sale of extra allowances would enter a separate account dedicated to the abatement of GHG through the acquisition of domestic offsets by the EPA, the sole purchaser of offsets.[5]

As the sole buyer dealing with many sellers, the EPA would be able to exercise considerable bargaining power in the negotiation of offset contracts. However, the EPA could face difficult management challenges as the flow of revenues to the dedicated account could be highly volatile. Depending on the price collar and the appropriation delays, the EPA could be in the offsets business one year and out of it the next. Anticipating such challenges is one of the goals for the simulation modeling described in this paper.

Main Purpose of this Paper

In my view, the CLEAR Act stands alone from the many carbon market proposals. The requirement for all allowances to be sold at auction from the beginning of the market is an important improvement over other proposals. The CLEAR Act would lead to higher prices of carbon based fuels in upstream providers, and the price signal would spread through the entire

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[4] Policy-makers are wise to address the challenge of achieving greater price stability. Recent experiences in a variety of energy and environmental markets teach us that newly created markets should incorporate clear provisions for limiting the dramatic swings in prices. Unfortunately, the study of price stability is a neglected area of analysis in the majority of economic modeling studies. Despite the evidence from recent market experiences, most economic models of carbon proposals continue to show price trajectories that leave policy-makers with the misleading impression that carbon prices will follow a smooth, highly predictable upward path. These trajectories are the inevitable result of extreme assumptions about energy companies' knowledge of future conditions in the energy system. The "perfect foresight" assumption allows the models to perform complex calculations, but the models are not useful for policy makers looking for an appropriate policy to provide price stability while achieving substantial reductions in emissions. The modeling method used at WSU takes a dramatically different approach. We avoid the perfect foresight assumption that prevents most economic models from dealing with price volatility. Our goal is to develop models that represent sources of carbon price volatility in a clear and realistic manner. We will then us the models to test the impact of different proposals to contain the price volatility.

[5] This approach changes the role of offsets in a fundamental fashion. The acquisition of offsets is transferred from regulated businesses looking to avoid emission reductions to the EPA. The acquisition of offsets is also transferred in time. Rather than occurring at the outset, offsets would not be acquired until after a demonstrated need for cost containment.

energy system. And the elimination of offsets would avoid the difficult and messy task of design and verification that offsets are delivering real benefits. The CLEAR Act is gaining increased attention in political deliberations[6] and in the business press.[7] It deserves increased attention by analysts as well.

The purpose of this paper is to initiate discussion of a computer simulation model that can be used to anticipate the challenges in the design and management of a cap and dividend proposal. The model can be used to simulate the CO2 emissions and the size of the dividend to the average US household. A crucial design question is the width of the price collar:

- A narrow price collar provides greater certainty on the price of allowances, but it can create instability in cash flows and a delayed achievement of the reduction in GHG emissions.
- A wide price collar could allow more room for the market to clear, and investors may be faced with major fluctuations in the price of allowances. But a sufficiently wide collar would guarantee that emissions of the regulated companies would comply with the cap, and there would be no need for the EPA to get into the offsets business to achieve delayed abatement of emission.

This paper describes an initial simulation model to test the effect of different price collars in scenarios with major swings in the price of allowances. The model will demonstrate the power of computer simulation to help us anticipate allowance prices, CO2 reductions and cash flows under the CLEAR Act. This paper is written to begin discussion of the best way to structure a computer model to aid in the design and management of a cap and dividend proposal.

Computer Simulation

Research at WSU is demonstrating the value of computer simulation modeling to help anticipate the impacts of carbon policies in the western USA. Previous modeling simulated the impact of the carbon prices envisioned in The Climate Stewardship Act of 2003 (Ford 2008). Our study focused on the western electricity market, the large interconnected market known as the WECC (Western Electricity Coordinating Council). The previous analysis was based on EIA (2003) estimates of the carbon prices that might emerge from S.139. Our study of the WECC confirmed what the EIA found for the nation as a whole – the electric power sector would lead the way in responding to carbon prices, and a major reduction in CO2 emissions could occur in the near-term from fuel switching between coal plants and gas-fueled combined cycle plants. This paper describes a system dynamics[8] model to build from the previous study of S.139. The model focuses on the price volatility that could occur if fuel switching is the primary factor in reducing CO2 emissions.

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[6] For example, the inclusion of a dividend provision in the American Power Act is often credited to the influence of the CLEAR Act.

[7] An excellent article appeared in the February 4, 2010 issue of T*he Economist*. It describes the CLEAR Act as a refreshingly simple alternative to the Waxman-Markey bill.

[8] System dynamics has proved especially useful for the simulation of planning and financial problems in the electric power industry (Ford 2002) and in the simulation of the western power system (Ford 2008). And offsets have been the subject of a recent system dynamics analysis by Bier (2010).

Model Structure

Fig. 1 shows the principal variables and their interconnections. The stocks and flows are best described with a numerical example. Let's begin with the auction revenues and work our way down the diagram to the annual dividend to a typical household.

Suppose the cap is 200 million MTCO2/year from the power sector and 600 million MTCO2 from other sectors. The total allowances sold would be 800 million MT per year. If the allowance price were $20 per MTCO2, the auction revenues would be $16,000 million per year. After a short dispersal delay, 75% of auction revenues are transferred to the Carbon Refund Trust Account. The cash flow in the refund direction would be $12,000 million per year. When this is paid out to 20 million households in the west, the average dividend would be around $600. The other 25% of the auction revenues would amount to $4,000 per year. This is cash flow to the Clean Energy Reinvestment Trust Fund, the CERT Fund. The model splits these funds between R&D and assistance projects, two of the many suggestions for the CERT funding.

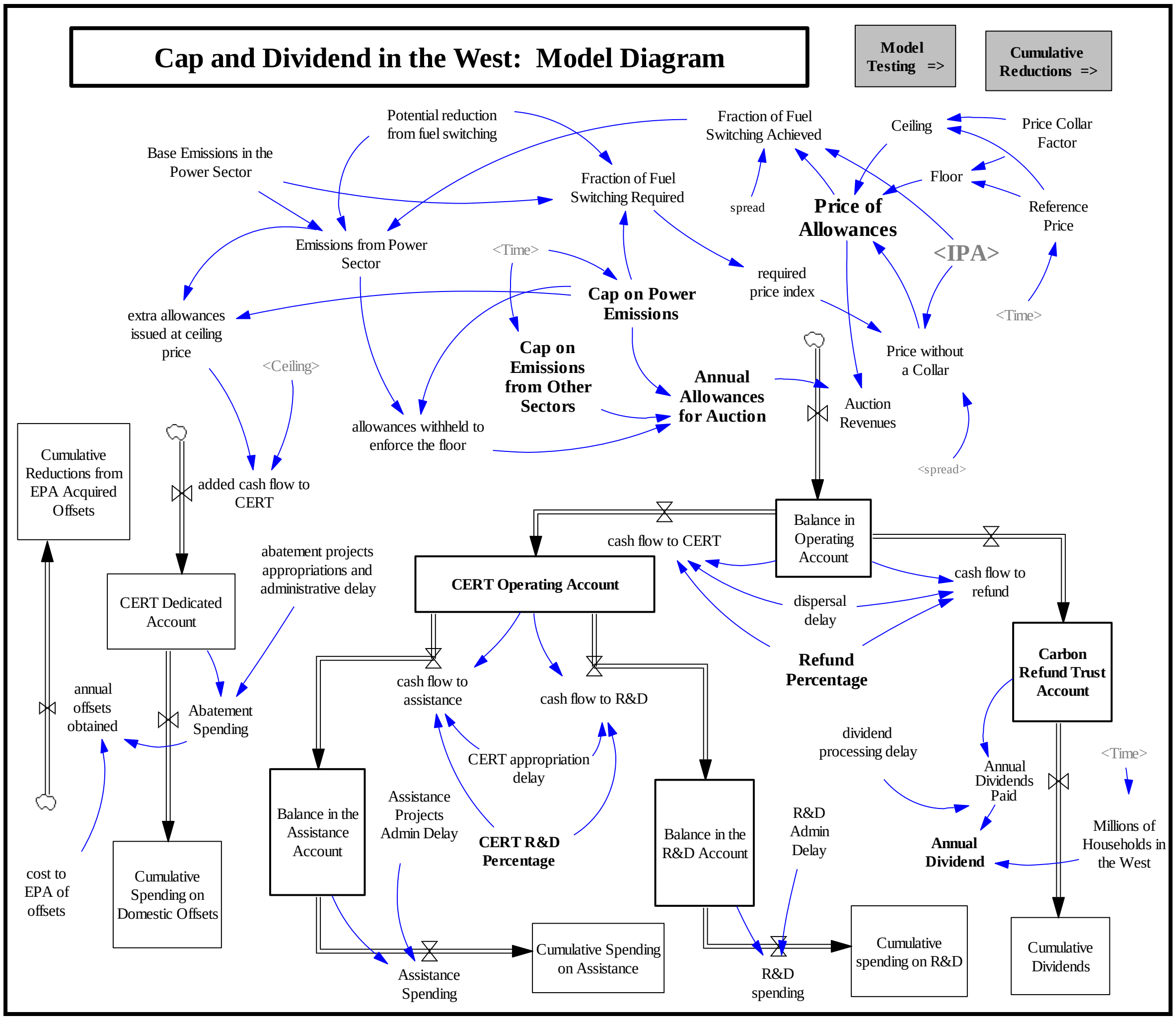

Fig. 1.Vensim diagram showing the main stocks and flows in the model.
(The financial stocks are measured in millions of $; the flows in millions of $/year.)

The CLEAR act calls for approximately a 10% reduction in total emissions in the US during the decade from 2012 to 2022. The base value of CO2 emissions from the western power system is around 300 million metric tons (MT) of CO2 per year. We assume that around one-third of the emissions in the west are from electric power. We know from previous studies (EIA 2003; Ford 2008) that the power sector is the primary player in cutting CO2 emissions. To keep the introductory model easy to understand, we start with the assumption that the power sector will dominate in cutting emissions and in setting the price. If the other sectors show negligible response to the carbon prices, we need to see a 30% reduction in power sector emissions if we are aiming for a 10% reduction in total emissions. The auctions begin in 2012, with the power cap just below 300 million MTCO2/year. During the next ten years, the cap is lowered to 200 million MTCO2/year. This is a 30% reduction which meets the intention of the CLEAR Act. Based on separate analysis of the WECC (Ford 2008), we know that a one-third reduction would require nearly 100% "fuel switching" between the coal and the gas fired CCs. In other words, to get a 30% reduction, we will need most of the coal plants to switch out of operation.

Fig. 2 shows the portion of the model to simulate the required fuel switching. A graphical display is included to depict the carbon prices needed to motivate the required fuel switching. The black lines show the variable cost of three types of coal plants. Their steep upward slope is based on the carbon content of coal and the heat rate of the plant. The coal lines increase by $10 per MWh for every $10 per MTCO2 increase in the allowance price. The thinner lines show the variable cost of a typical combined cycle plant fueled by natural gas. Their upward slopes are based on the carbon content of natural gas and a typical heat rate for the power plant. Their slope is 36% as steep as the lines for coal.

The intersection points in Fig. 2 tell us the carbon price needed to induce fuel switching. This is called the IPA, the Indicated Price of Allowances in the model. Typical values include:

- the IPA is around $20 per MTCO2 if gas costs $4 per million BTU
- the IPA is around $30 per MTCO2 if gas costs $5 per million BTU
- the IPA is around $40 per MTCO2 if gas costs $6 per million BTU

The price of natural gas will be selected based on one of three scenarios. The gas price is combined with the other variables in Fig. 2 to find the intersection point on the variable cost curves in the graphic display. The IPA can be found by simple algebra, and then transferred to Fig. 1 where it is used to calculate the actual price of allowances. The price of allowances will be higher than the IPA if the cap on emissions calls for fuel switching greater than 50%. The price of allowances will be below the IPA if the cap can be satisfied with less than 50% fuel switching.

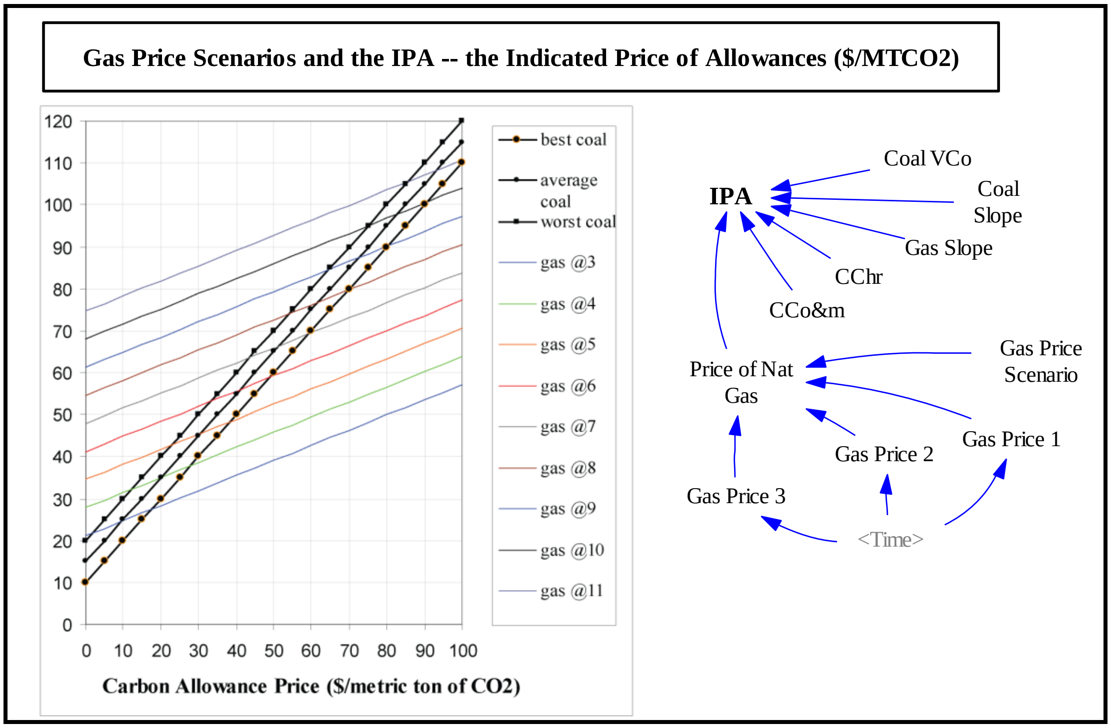

Fig. 2. Finding the IPA, the Indicated Price of Allowances for 50% fuel switching.

The price needed to meet the fuel switching requirement is called the "Price without a Collar." But the actual price of allowances is subject to a user specified price collar. We start with an exogenous reference price which will grow over time. The reference is set at $15 per MTCO2 when the simulation begins in 2012. The price collar factor is set at 0.5 to represent a plus-or-minus 50% price collar For example, the simulation begins with the ceiling price at $15*1.5 which is $22.5; the floor price would be $15/1.5 which is $10. The reference price climbs in a linear manner, reaching $40 per MTCO2 by the year 2027. With a 0.5 collar factor, the ceiling price would be $60 and the floor price would be $26.67. The model has been used to examine a wide range of scenarios with different gas prices[9] and different collars shown in Table 1. The natural gas prices and the implications for the allowance prices are shown in Fig. 3.

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[9] Gas prices have been highly volatile in the past, and they could be highly volatile in the future. In the interest of clarity, this paper uses the price of gas as the sole source of uncertainty in the carbon market. The US wellhead natural gas price is around $4 per million BTUs, according to the Draft 6th Power Plan of the Northwest Power Planning Council (NPPC). All three gas price scenarios in this paper begin with gas at $4 per million BTUs so the price of allowances for 50% fuel switching will be around $20 per MTCO2 at the start of the three simulations.

identifier	Gas Price Scenario	Price Collar
gas1	1st scenario: The gas price reaches $6.5 by 2027, following a trajectory between the medium and medium-low scenarios.	The price collar factor is set at 0.5, and the price of allowances remains within the collar.
gas2	2nd scenario: The gas price climbs to $8 by the 2027 -- similar to the med-high scenario	With the collar factor at 0.5, there will be pressure on the price ceiling.
gas2 wider	2nd scenario	The collar factor is increased to 1.0; the price remains within the collar
gas3	3rd scenario: The gas price follows a cyclical pattern outside the range of the scenarios.	With the collar at 0.5, there will be pressure on both the floor and the ceiling.
gas3 wider	3rd scenario	With the collar at 1.0, the floor price will no longer apply, but there will continue to be pressure on the ceiling.
gas3 much wider	3rd gas price scenario	With the collar at 1.5, the price of allowances will remain within the collar.

Table 1. Assumptions for the price of natural gas and the price collar.

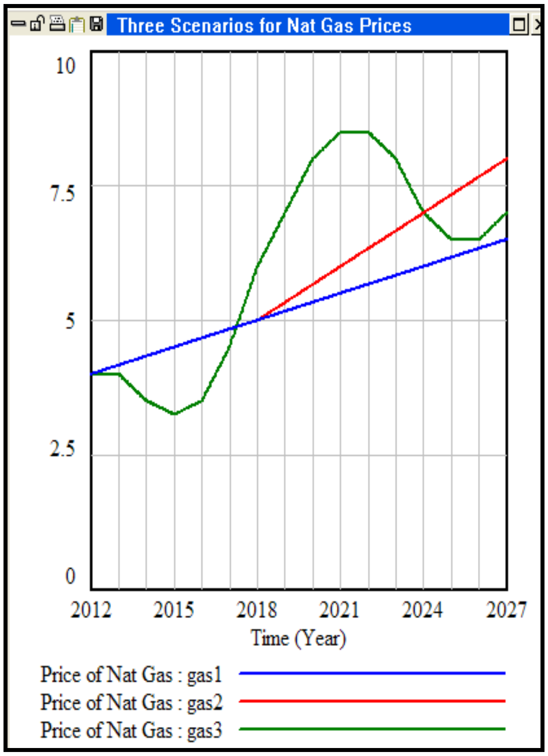


Fig. 3A. Price of natural gas
in the three scenarios.
(The price is in $ per million BTU).

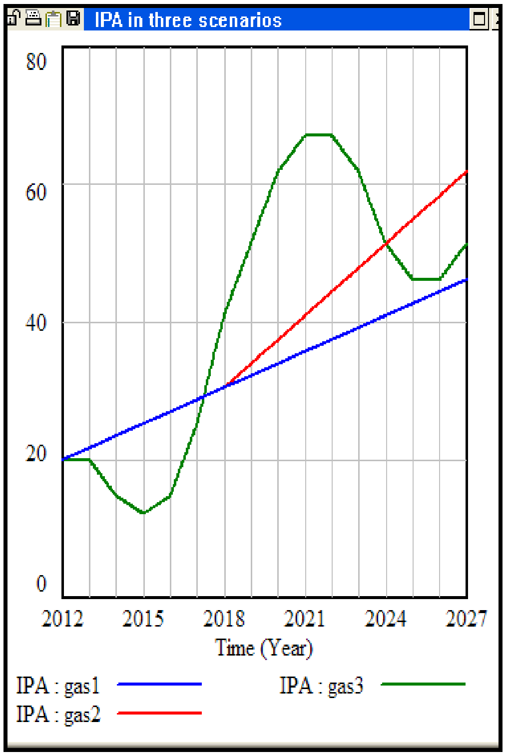
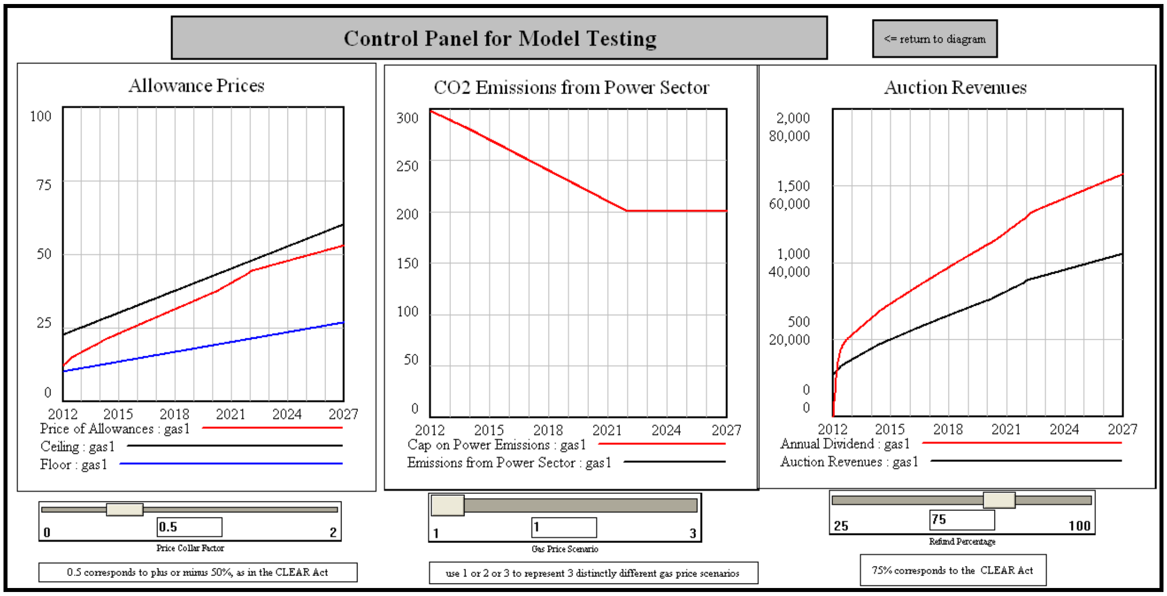


Fig. 3B. Indicated price of allowances
in the three scenarios.
(The price is in $ per MTCO2).

First Simulation: The Allowance Prices Remain Within the Collar

Fig. 4 shows the view of the model's "control panel" in the first simulation. These "sliders" are shown in Fig. 4. These allow for easy experimentation with different values of the model inputs. The sliders alert us that this simulation uses the 1st of three gas price scenarios with the price collar factor set to 0.5 to represent the plus or minus 50% price collar envisioned in the CLEAR Act. The refund percentage is at 75% as proposed in the CLEAR Act.



Price Collar Factor 0.5

Gas Price Scenario 1

Refund Percentage 75

0.5 corresponds to plus or minus 50%, as in the CLEAR Act

use 1 or 2 or 3 to represent 3 distinctly different gas price scenarios

75% corresponds to the CLEAR Act

Fig. 4. First simulation: a point of comparison for other simulations.
(The sliders show we are simulating the 1st gas price scenario with the price collar factor @0.5 and 75% of the auction revenues refunded. The allowance prices are measured in \$/MTCO2; the emissions in millions of MTCO2/year; the auction revenues in millions of \$/year; and the dividend in \$/year per household).

Fig. 4 shows simulation results in time graphs for the allowance prices, the CO2 emissions and the auction revenues. The legend alerts us that the results come from gas1, the identifier for the first of the six cases in Table 1. The first graph shows that the price of allowances will grow over time and remain in the collar. The second graph confirms that emissions from the power sector are identical to the cap.[10] Power sector emissions fall from around 300 to 200 million MTCO2/year. The third graph shows auction revenues climbing to around \$40,000 million per year near the end of the simulation. The annual dividend for an average family of four would reach \$1,000 midway through the simulation and exceed \$1,500 near the end of the simulation.[11]

Fig. 5 shows control panel in the simulation with the 2nd gas price scenario and the collar factor at 0.5 (to represent plus or minus 50%). The allowance price is controlled by the ceiling price in the later years of the simulation, and the power sector emissions exceed the cap.

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[10] The power emissions are displayed by a black line, the cap by a red line. The black line is hidden below the red line and not visible in Fig. 4.

[11] An average household dividend of \$1,000 per year is often mentioned in discussions of the CLEAR Act.

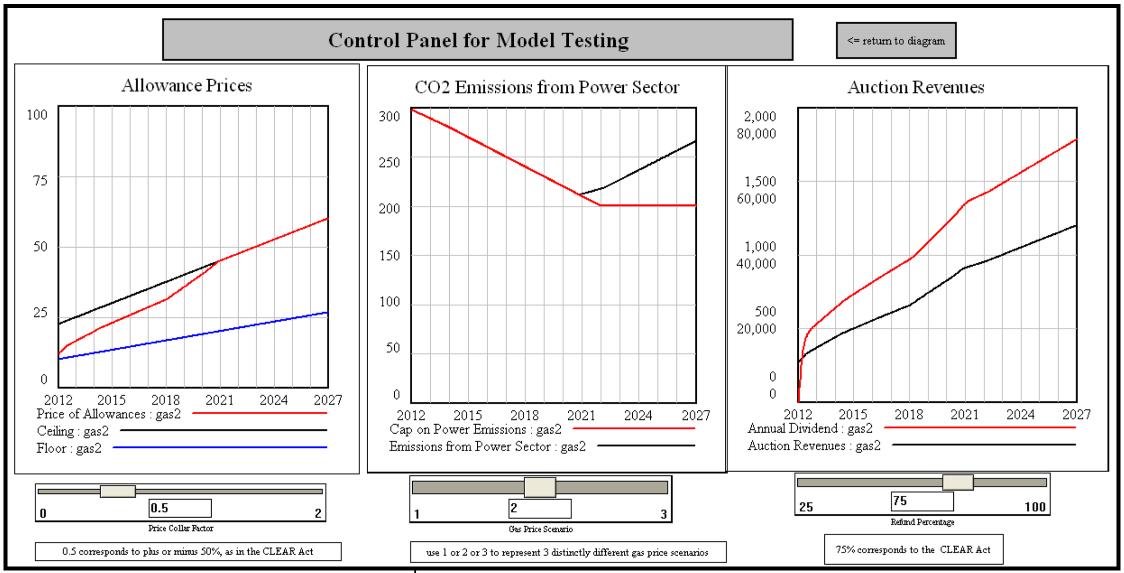


Fig. 5. Results of the 2nd gas price scenario with the normal price collar.

Fig. 6 shows control panel in the simulation with the 3rd gas price scenario and the collar factor at 0.5. The low price of natural gas causes the allowance price to be controlled by the floor for two years early in the simulation. Allowances are withheld during this period, and the emissions fall below the cap. Auction revenues and the annual dividend also fall during this two-year period as fewer allowances are sold at auction. The high price of natural gas in the later years causes the price to remain at the ceiling for four to five years. CO2 emissions are well above the cap during these years because the allowance price is not sufficient to trigger any fuel switching.

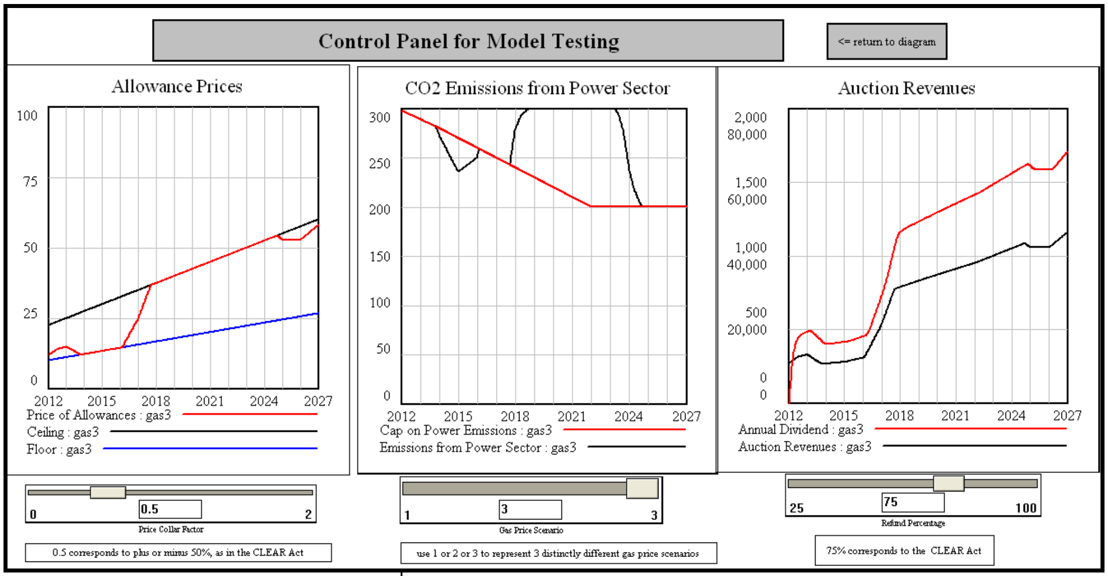


Fig. 6. Results of the 3rd gas price scenario with the normal price collar.

Figs. 7 and 8 show the changes in the price collar that would be needed to allow allowance prices to trigger the needed fuel switching in the 3rd scenario. Fig. 7 uses a price collar factor of 1.0 to allow plus or minus 100%. With this "wider collar," the floor price is not active during the period of low gas prices. The time graph shows that the ceiling price would be enforced for around four years during the simulation.

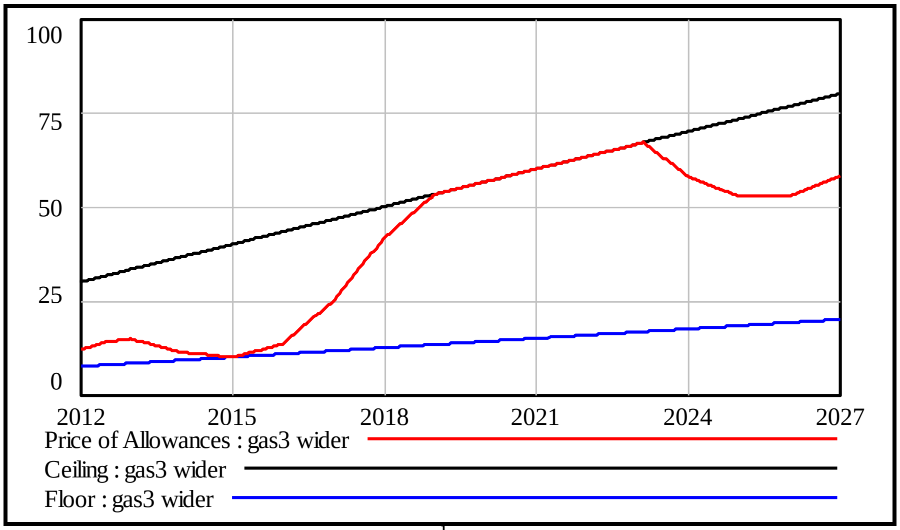


Fig. 7. Allowance prices with the 3rd gas price scenario and a wider collar.

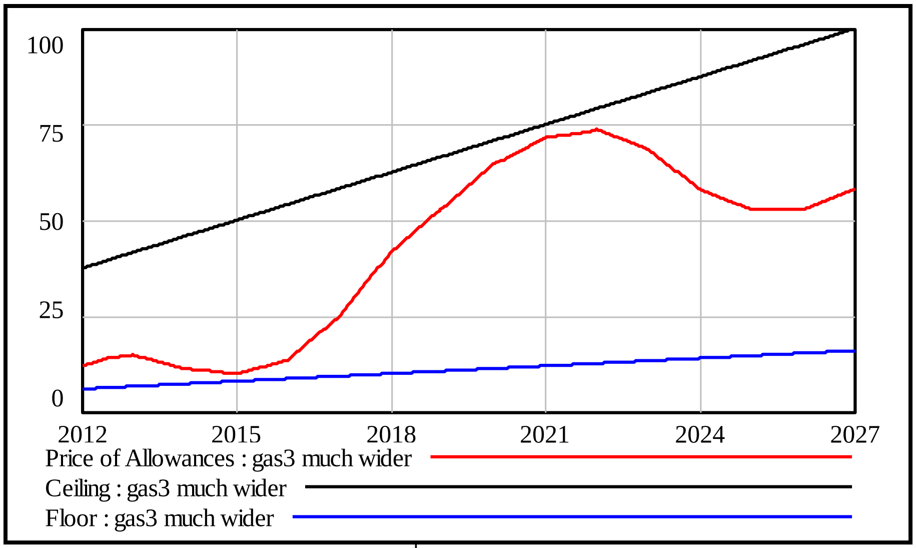
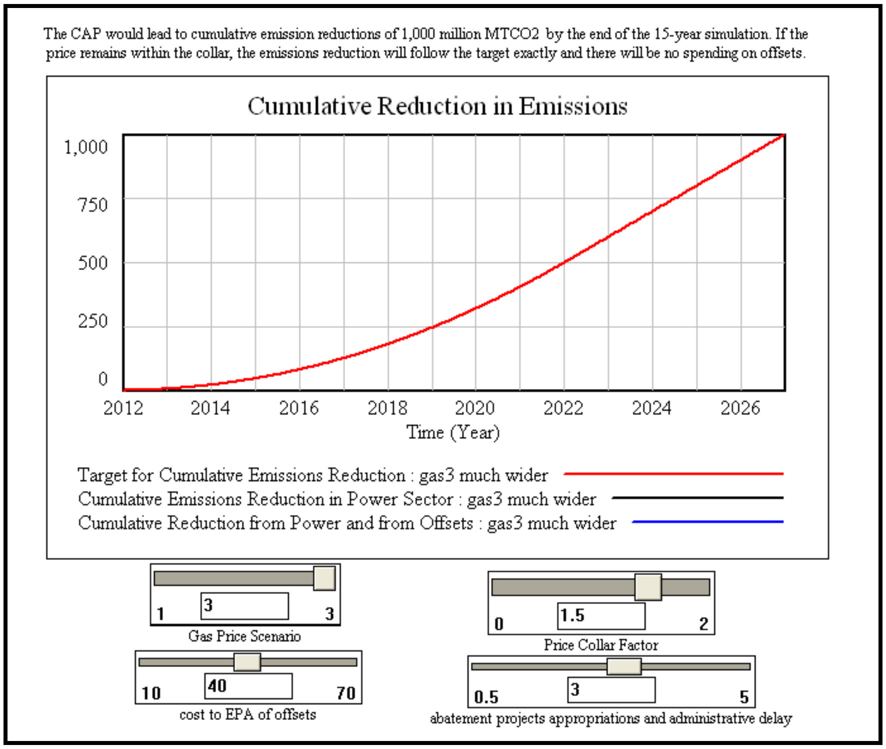


Fig. 8. Allowance prices with the 3rd gas price scenario and a much wider collar

Fig. 8 shows the 3rd gas price scenario with the collar price set to 1.5 to allow plus or minus 150%. The ceiling price would start at around $37 in 2012 and climb to $100 by the end of the simulation. Fig. 8 shows the price of allowances remaining within this “much wider collar, so the emission reductions in the power sector will match the reductions needed to comply with the cap.

Cumulative Reductions in Emissions

The emission reductions required in this paper would lead to cumulative reductions of 1,000 million MTCO2 by the end of the simulations. Fig. 9 shows the cumulative[12] reduction in emissions in with the 3rd gas price scenario and the "much wider collar." We know from Fig. 8 that the price of allowances would remain within the collar in this scenario, so we would expect the simulated market to respond with emission reductions that achieve the cap in each and every year.[13] The red curve in Fig. 9 shows the target for cumulative emissions. It climbs slowly at first and then accelerates, eventually reaching the goal of 1,000 million MTCO2 by the end of the simulation. Cumulative emissions from the power sector are represented by the black curve. This curve is identical to the red curve, so it is not visible in Fig. 9. Since the allowances market is operating within the price collar, there is no need for the EPA to acquire offsets, and the blue curve is also identical to the target.



The CAP would lead to cumulative emission reductions of 1,000 million MTCO2 by the end of the 15-year simulation. If the price remains within the collar, the emissions reduction will follow the target exactly and there will be no spending on offsets.

Gas Price Scenario: 3

Price Collar Factor: 1.5

cost to EPA of offsets: 40

abatement projects appropriations and administrative delay: 3

Fig. 9. Cumulative emissions from the power sector are on target in the simulation with the 3rd gas price scenario and the "much wider collar."

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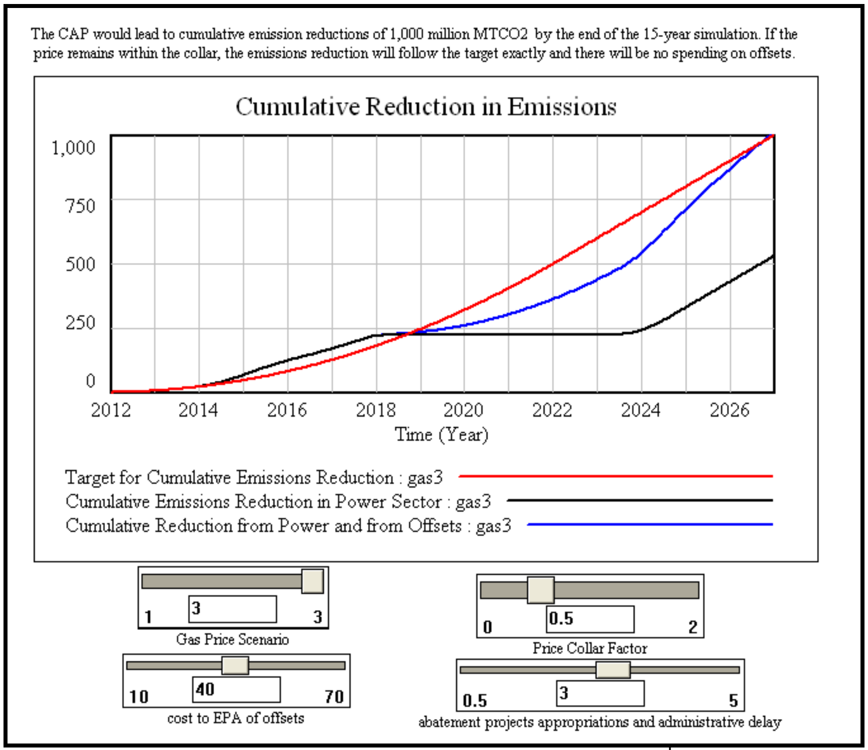
[12] The cumulative reductions are the important measure of the effectiveness of carbon policies that aim to reduce the threat of climate change from excessive emissions of CO2. With an effective atmospheric life of around 100 years for CO2, it makes sense to focus on cumulative reductions. The cap specified in this model calls for cumulative reductions of 1,000 million MTCO2. The goal is one billion MTCO2. And since the analysis includes domestic offsets, the total goal would be measured as one billion MTCO2e.

[13] The simulation model does not deal with banking of allowances which can lead businesses to reduce emissions more aggressively in the short-term on the expectation that allowance prices will be higher in the long-term.

Fig. 10 shows the cumulative results with the 3rd price scenario with the 50% price collar envisioned in the CLEAR Act. We know from the left graph shown previously in Fig. 6 that the price floor would be in effect in the early years of the simulation, and the price ceiling would be in effect for much of the 2nd half of the simulation. The middle graph shown previously in Fig. 6 shows the year by year emissions from the power sector. They would be lower than the target when the price floor is enforced and much higher than the target when the ceiling is enforced. Fig. 10 shows the cumulative results, including the effect of the offsets acquired by the EPA using the funds in the CERT dedicated account.



The CAP would lead to cumulative emission reductions of 1,000 million MTCO2 by the end of the 15-year simulation. If the price remains within the collar, the emissions reduction will follow the target exactly and there will be no spending on offsets.

Gas Price Scenario: 3 (1 to 3)

Price Collar Factor: 0.5 (0 to 2)

cost to EPA of offsets: 40 (10 to 70)

abatement projects appropriations and administrative delay: 3 (0.5 to 5)

Fig. 10. Cumulative reduction in emissions with the 3rd gas price scenario and the plus or minus 50% price collar envisioned in the CLEAR Act.

The red curve in Fig. 10 is the target for cumulative reductions. It reaches 1,000 million MTCO2 by the end of the simulation. The black curve shows the cumulative reduction from the power sector. It exceeds the target during the interval from 2015 to 2018, the period when the market price would fall below the floor price. The floor is enforced by the withholding of allowances for sale during this period, and emission reductions exceed the normal target.

The steep rise in natural gas prices in the second half of the simulation drives the market clearing price of allowances to the ceiling, and the administrator responds by issuing additional allowances to enforce the ceiling. The black curve in Fig. 10 shows no growth in cumulative reductions for the period from 2018 to 2024. The bottom left corner of Fig. 1 reminds us that the extra allowances issued at the ceiling price generate added cash flow to CERT. This cash flow goes to a dedicated account for abatement spending. The sliders in Fig. 10 indicate a three year appropriations and administrative delay before these funds are put to use in acquiring domestic offsets (at the price of $40 per MTCO2e). The sum of the power sector reductions and the offsets is the blue curve in Fig. 10. It grows quite slowly after 2020 due to the appropriations delay. But the cumulative effect of EPA's abatement efforts will build over time, and the cumulative reductions will reach the target of 1,000 million MTCO2e by the end of the simulation.

Fig. 11 provides more information on the challenge faced by EPA in the 3rd gas price scenario and the plus or minus 50% collar. The red curve shows the added cash flow from the sale of extra allowances to enforce the price ceiling. There is no cash flow until the year 2018, the first year to test the price ceiling. The red curve shows substantial funds flowing into the account, reaching a peak of $5,000 million per year around the year 2022. The cash flow into the account declines quickly to zero around 2023-2024 when gas prices have fallen and there is no further need to enforce the ceiling.

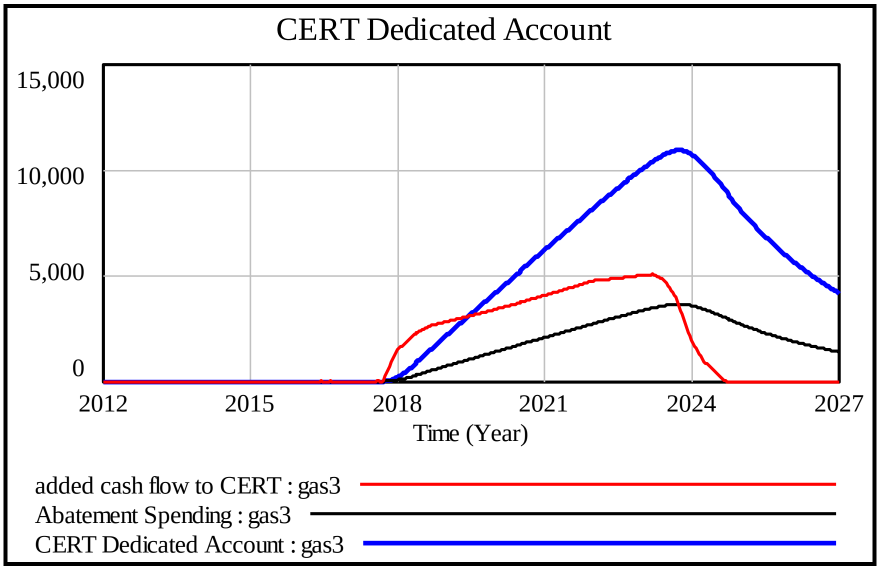


Fig. 11. Closer look at the CERT dedicated account in the simulation with highly volatile gas prices and the plus or minus 50% collar.

The blue curve in Fig. 11 shows the balance in the CERT dedicated account. It climbs rapidly during the period from 2018 to 2023 due to the rapid inflow of funds and the delays in appropriation and administration. The balance in the fund would peak at around $11 billion in 2023, around the time when gas prices are falling and there is less need to enforce the collar.

The black curve in Fig. 11 shows the EPA spending on abatement projects. It peaks around 2024 and declines slowly during the final years of the simulation. This simulation assumes that the EPA can obtain domestic offsets at the cost of $40 per MTCO2e. These emission reductions make it possible for the total emission reductions to reach the ultimate target of 1 billion MTCO2e by the end of the simulation.

This particular simulation tests the CLEAR Act in a scenario with highly volatile allowance prices and the plus or minus 50% collar. Fig. 10 indicates that the emissions target could be achieved through a combination of power sector reductions and domestic offsets acquired in the later years of the simulation. Fig. 10 alerts us to expect a delayed achievement in the emissions reductions due to the delays in appropriation and administration of the dedicated CERT account. However, given the longevity of CO2 in the atmosphere, the delayed achievement of the cumulative target is not a serious problem. On the other hand, the substantial accumulation of unspent funds in the dedicated account could focus criticism on the EPA. Fig. 11 teaches us to expect such large accumulations when the ceiling price is enforced over a long interval and there are major delays in appropriation and administration.

Volatility in the Allowance Prices and the Annual Dividend Payments

Figs. 12 and 13 conclude the illustrative analysis by showing the variability in the allowance prices and the annual dividends. The 1st gas price scenario is shown in blue. It provides a point of comparison for the impact of different gas prices and different policies on the collar. The most revealing simulations involve the 3rd scenario for natural gas prices. This scenario calls for highly cyclical natural gas prices as a test condition. The goal is to see the volatility in allowance prices and the effectiveness of the price collar in containing that volatility. The greatest volatility appears in the purple curve, which represents the simulation with the cyclical gas prices and the "much wider collar." Allowance prices peak in the year 2022 at around $74 per MTCO2.

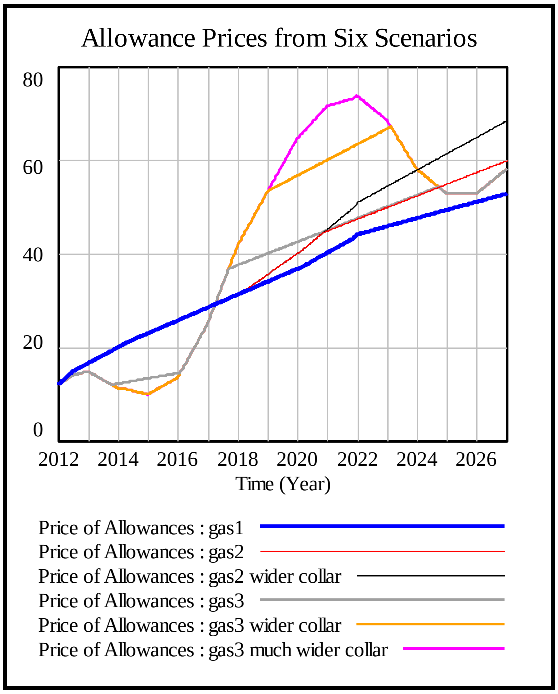


Fig. 12. Allowance prices ($/MTCO2).

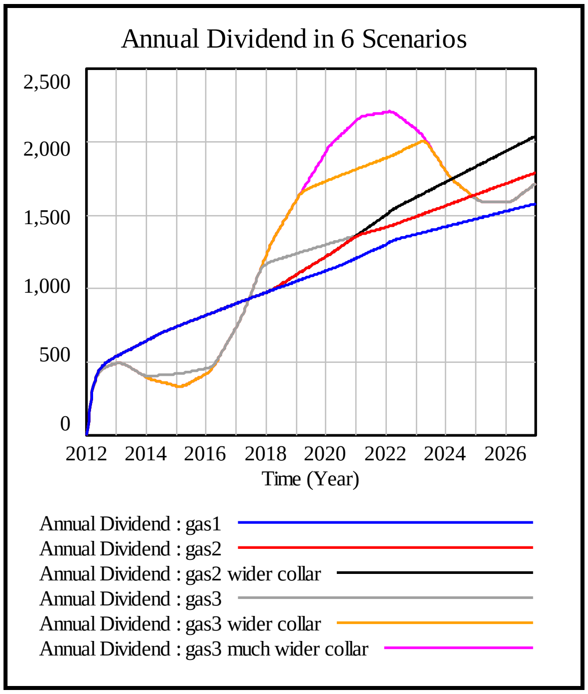


Fig. 13. Annual dividends ($/year per household).

Fig. 13 shows the variability in annual dividends to the average household. This graph indicates that the highest annual dividend that would appear around 2022 with the purple curve, the curve for the 3rd gas price scenario and the much wider collar. With allowance prices selling at $74 per MTCO2, the cash flow to the Carbon Refund Trust Account would be much higher. Indeed, the annual dividend to a typical household would peak at around $2,200 shortly after the peak in allowance prices in this scenario.

The key features of Figs. 12 and 13 is the close correspondence of the curves. We see the same pattern in the two graphs regardless of the gas price scenario or the width of the price collar. The similarity of the patterns indicates that the household dividends will rise and fall in sync with the rise and fall in allowance prices. The close similarity is important for households to be shielded from the higher energy prices that will work their way from the upstream energy companies to the sale of energy at retail.

Summary

This paper provides a short summary of an introductory computer model to simulate the impacts of a cap and dividend approach to carbon policy. The illustrative simulations focus on the impacts of the CLEAR Act in the western USA. The simulations portray the volatility of the carbon market due to variations in the price of natural gas and the design of the price collar.

The model described here is a starting point for work planned at WSU. These results will be shared with analysts, experts and policy makers to encourage suggestions for the best way to expand and improve upon what has been presented here.

Appendix A. Green Stimulus Spending

The news headlines in early 2010 are filled with announcements of government programs to create new jobs and to spur economic growth, especially growth in recycling, carbon reduction, energy conservation, river management and protection of natural resources. The South Korean government recently announced a “Green New Deal” with $38 billion in spending and a plan to create 956 thousand jobs. The Japanese environment ministry announced a similar plan with a similar label. Their “Green New Deal” would create one million new jobs in energy-savings and environment-friendly technologies. The Japanese Minister of the Environment (Saito 2009) describes “the innovation for green economy and society” to realize a “low carbon society,” a “sound material-cycle society” and a “society in harmony with nature.” The innovations are expected to foster an environmental market which will reach 120 trillion yen by the year 2020. Environmental jobs are expected to double from 1.4 million to 2.8 million during by the year 2020.

The initiatives in South Korea and Japan are part of a world-wide effort promoted by the United Nations under the slogan of a “Global Green New Deal.” The term “Green New Deal” is an adaptation of the “New Deal” of the Franklin Roosevelt administration. Unemployment was quite high in the US during the 1930s, a time known as the “Great Depression.” Roosevelt’s “New Deal” included government spending on infrastructure designed to provide jobs. The spending was particularly important in the development of massive hydro-electric resources in the Pacific Northwest and in the South East. The initiatives of 2009 and 2010 are called the “Green New Deal” because governments (ie, in the USA, Korea, Japan) are hoping that economic stimulus funding will lead to both new jobs and a modernized infrastructure to enable the transition to a more efficient, carbon-free energy system.

Renewable energy is the focus of both government and private initiatives, and Fig. A-1 provides a summary (Pew Charitable Trust 2010) of the renewable investment of the "G-20" countries. China leads the world in Fig A-1a, where the combination of wind, small hydro, biomass and waste exceeds 50 GW. The US led the world in installed wind, biomass and geothermal capacity. Germany is the undisputed leader in solar with 5.3 GW of capacity. Japan and Spain have substantial solar investment, around 2.1 GW each.

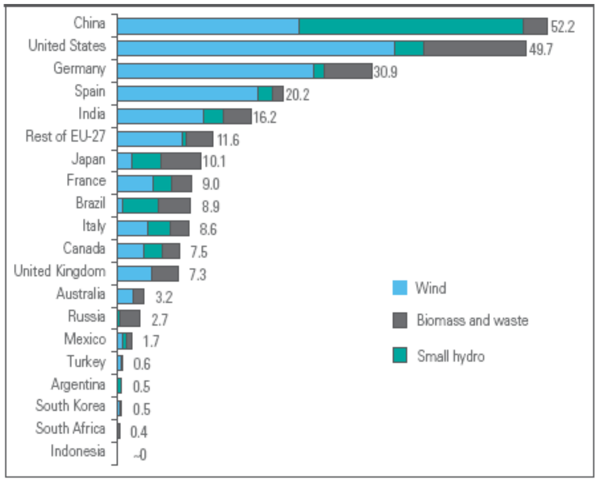


Fig A-1a. GW of installed renewable capacity (wind, small hydro, biomass and waste) in the G-20 countries in 2009.

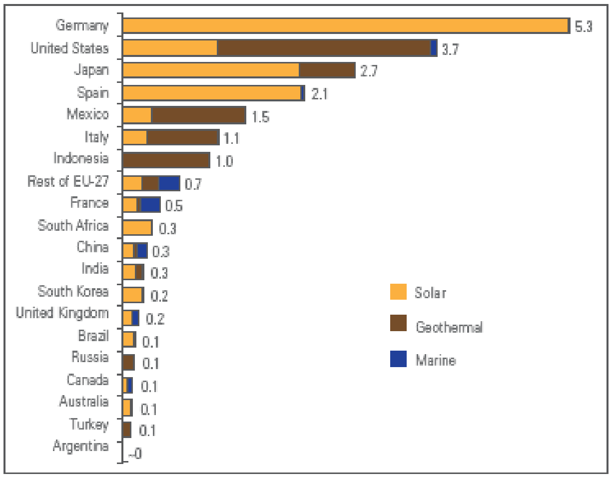


Fig. A-1b. GW of installed renewable capacity (solar, geothermal and marine) in the G-20 countries in 2009

The Pew (2010) report characterizes the G-20 countries as participating in a "race" for competitive position in the clean energy sector, a sector which has grown by 230% since the year 2005. The Pew report took special note of China's growing investment in green energy. China doubled its wind capacity in 2009 in pursuit of the ambitious target of installing 30 GW by the year 2020. Last year's clean energy spending in China was estimated at nearly $35 billion (compared to less than $20 billion in the US).

Appendix B. System Dynamics Study of Tradeable Green Certificates

A tradeable green certificate (TGC) is issued to renewable generators for each megawatt-hour (MWH) of generation. The TGC can then be sold to distribution companies who are obliged to turn in TGCs to comply with a mandate for a percentage of their generation to come from renewable sources. Advocates of TGCs would be traded in a market that would operate separately from the wholesale electricity market. Wind developers (and other renewable developers) could sell the TGCs in one market and the electric energy in the wholesale market. If they could earn $55 per MWh in the wholesale electric market and $15 per MWh in the TGC market, the combined revenue of $70 per MWh would be sufficient to cover the total, levelized cost of wind development.[14]

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[14] The wind costs were based on an assessment of costs of new wind farms in the Pacific Northwestern region of the USA in 2005.

An alternative way to encourage the development of new wind generation is the fixed feed-in tariff. If wind developers face a total cost of $70 per MWh, regulators could simply require that the electric distribution companies pay wind companies $70 for each MWh of generation. This administrative approach is popular in the European countries shown in green in Fig. B-1. Countries like Germany and Spain have achieved dramatic increases in installed wind capacity with this direct administratively specified incentive. As of 2005, countries like the UK and Italy were experimenting with the market based approach of trade in TGCs. The red bar in Fig B-1 makes it clear that these countries have little capacity to show for their efforts.

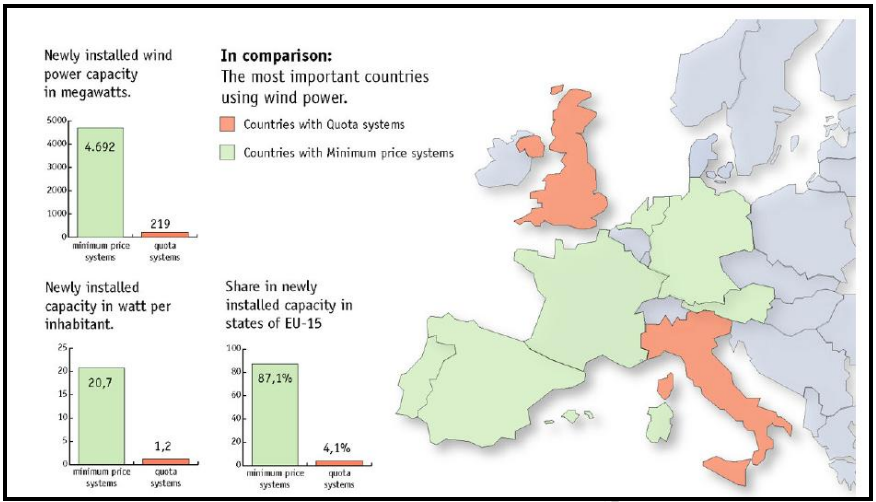

Fig. B-1. Wind capacity comparison in European countries[15] with a fixed incentive (in green) and with a market-based quota incentive (in red).

The WSU study of TGCs was initiated to anticipate the possibility variability in market prices around the fundamental price of $15 per MWh mentioned previously. Fig. B-2 shows the possible patterns of behavior of a new market that might open for business in 2006 and be used to motivate compliance with an increasing requirement for wind generation over the decade from 2006 to 2016. This sketch of possible behavior patterns is the "reference mode" for the system

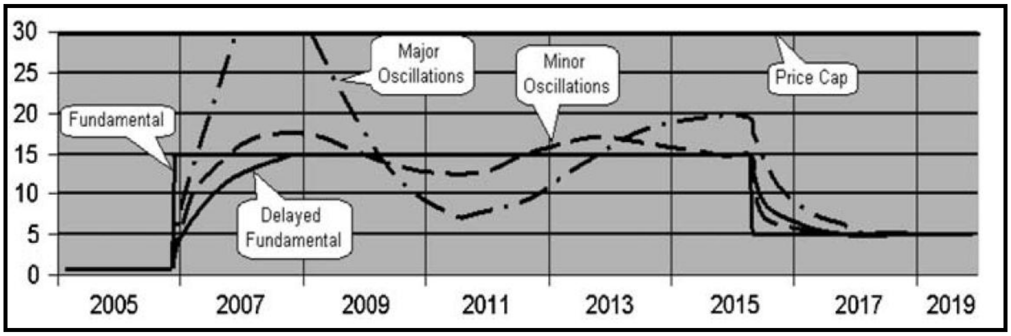

Fig. B-2 Reference mode for the simulation of TGCs.

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[15] This comparison is from 2005, with data from the European Renewable Energies Federation, the World Watch Institute and the Bundesverband Wind Energie. The incentive policies may have changed since 2005, and the wind capacities are certainly much higher than five years ago.

dynamics study. The drawing of such a target pattern at the outset of a system dynamics study is a common practice in the system dynamics community (Ford 2009, p. 50), but it is entirely uncommon to the community of energy analysts. Indeed, raising the possibility that the TGC price would not automatically find its way quickly to the fundamental value of $15 per MWh separated our analysis of TGCs from the many other studies in the energy policy and energy economics literature.

Fig. B-3 shows the core structure of the model to simulate TCG prices under highly controlled conditions in which both the generating companies (GenCos) and the distribution companies (DisCos) are familiar with the $15 per MWh price and with the amount of wind capacity and wind construction relative to the state mandate.

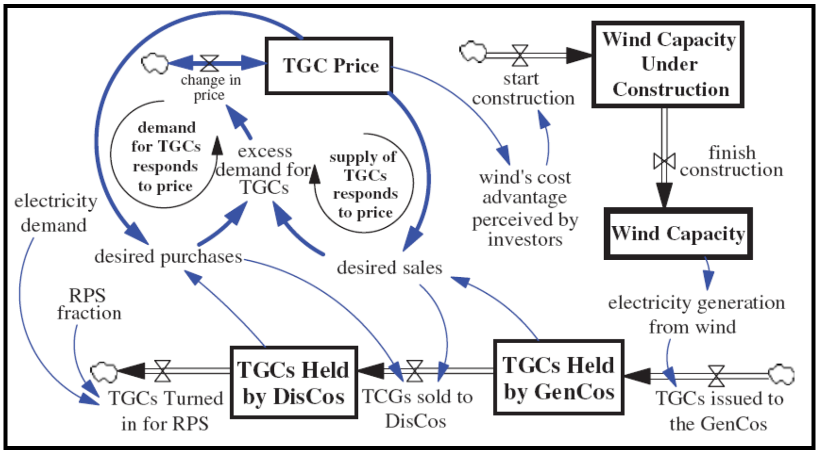


Fig. B-3. Core structure of the model of TGCs.

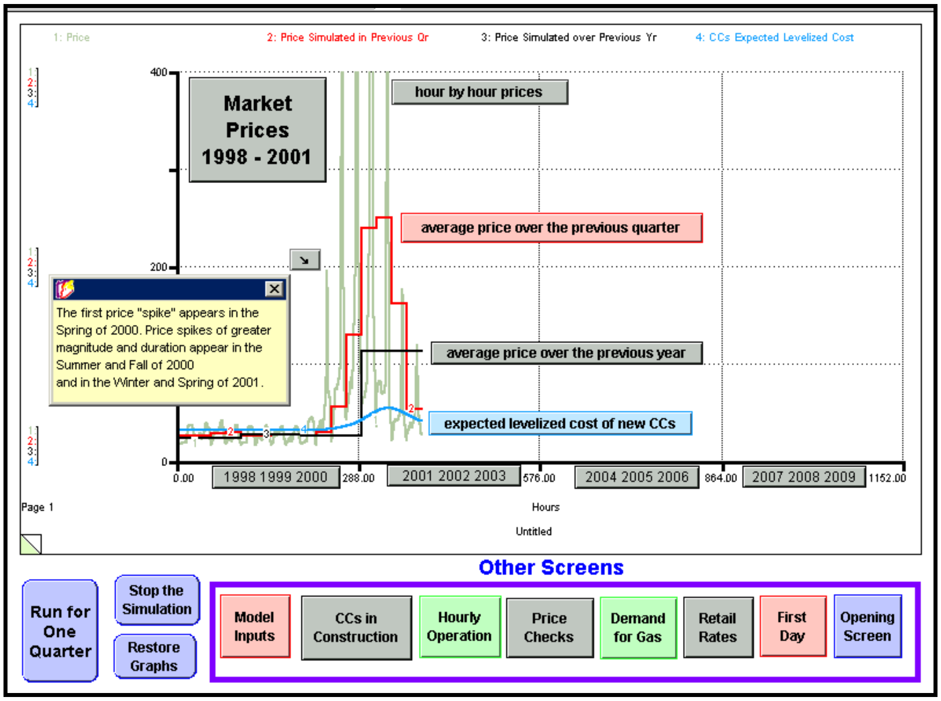
Fig. B-4. TGC price in a simulation with highly controlled conditions that offer a good opportunity for the market to find the fundamental price.

Fig B-4 shows the surprising simulation of the model under the highly controlled conditions. The TGC price rises rapidly when the market opens in 2006 and shoots past the fundamental price of $15 per MWh. The price rise is limited by the $30 per MWh “price cap”, the administrative limit on the market. The price remains at the cap for several years sending a highly encouraging signal to wind investors. The model responded with a delayed surge in wind construction and wind capacity eventually exceeding the mandated targets. TGC prices fell below the fundamental price. Fig B-4 indicates the market price would not find its way closer to the fundamental price around half-way through the ten-year interval.

The volatility in prices shown in Fig. B-4 reinforced the arguments of countries that support investment in renewable generation through administrative incentives. To the extent that they can maintain stable political support for the fixed incentive, their policy sends a more stable signal to motivate investment in new wind generation. For those countries that wish to experiment with a TGC, market-based approach, the WSU study revealed the need for a price cap to limit the price excursions and for the market administrator to develop a serious plan for the disposition of revenues obtained when extra certificates are sold at the ceiling price.

Appendix C. System Dynamics Study of a New Market for Electric Power in California

System dynamics has been used to understand the tendency for power plant construction to appear in waves of boom and bust in the restructured electricity market created in California in the late 1990s (Ford 2002). The new wholesale market opened for business in 1998, and prices were somewhat lower than required to justify new investment for around two years. Wholesale prices then increased rapidly in the year 2000 reaching values far beyond what would be needed to justify new investment. Fig C-1 shows a simulation of these historical wholesale prices over the interval 1999-2001.[16]



The first price "spike" appears in the Spring of 2000. Price spikes of greater magnitude and duration appear in the Summer and Fall of 2000 and in the Winter and Spring of 2001.

Fig. C-1. Simulation results over 1999-2001 in presentations from 2001.

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[16] This "screen capture" of the model interface was limited to 1999-2001 to show the historical period of results used in presentations at west coast agencies in the year 2001.

Fig. C-2 shows the dynamics of power plant construction over the entire simulation interval. The red line shows megawatts (MW) of new capacity under construction (with the red buttons showing historical targets used to check the model). The blue line shows the new capacity that has completed construction and is available for generation. The boom and bust pattern is evident from a comparison of the red line with the green line (a steady amount of new capacity under construction if construction were initiated by planning of capacity additions to meet a reserve margin for reliable service). The red line lags below the green line during 1998 and 1991 which set the stage for price spikes that appeared in 2000 and 2001. The red line exceeds green line for the next three years. This is the boom phase of boom and bust. Fig. C-2 then shows that the bust period is followed by another construction boom which sets the stage for the next bust in construction.

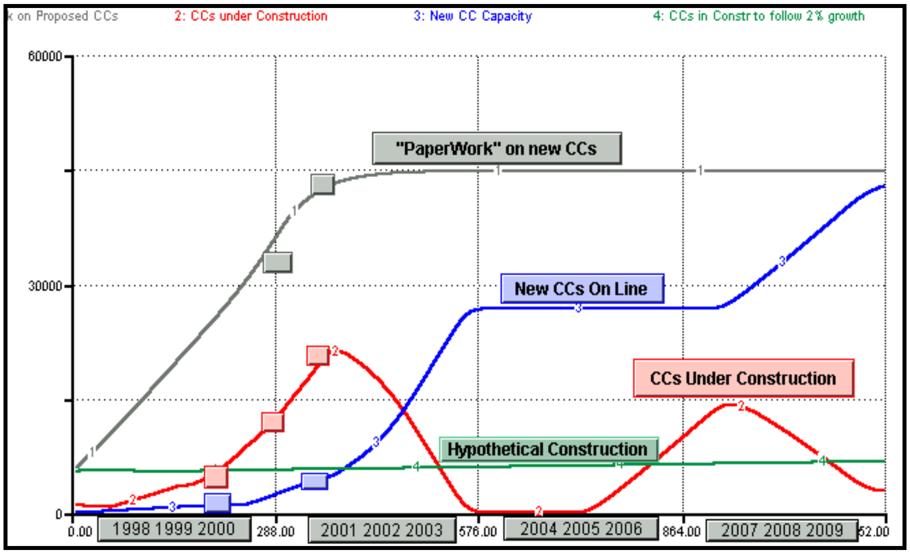

Fig. C-2. Boom and bust in power plant construction from simulations presented in 2001.

For the policy discussions in 2001, the most important implication of this pattern is that the initial problems of 2000-2001 were not a one-time event that might be associated with early market “teething” and therefore not likely to reappear in the future. Rather, the simulations showed that the boom and bust (and the accompanying problems of price spikes and unreliable electricity generation) could be a reoccurring event.

Changes in the market were required to avoid a reoccurrence of the crisis conditions of 2000-2001 (Ford 2002). Our recommendation was for a fixed capacity payment to supplement the market signal from the energy price in the newly created wholesale market. This payment would be set by market administrator, and it would provide a fixed signal that would add to the market signal from the wholesale energy market (ie, the prices in Fig. C-1). The combination of signals was simulated to deliver a steadier pattern of construction, one that could deliver the reserve margins needed for reliable electricity generation. [17]

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[17] This recommendation is not limited to the California analysis presented in 2001. Similar results were obtained in simulations of the proposed deregulation of the Korean electricity market in 2003 Similar findings were also obtained by Kadoya (2005) in work supported by the Kansai Electric Power Company (Osaka, Japan) and in work by Olsina (2006) supported by the national Council for Science and Technology in Argentina. The common denominator of these studies is the use of system dynamics simulation with an explicit theory of investor behavior.

Appendix D. The Climate Stewardship Act of 2003

The first carbon policy proposal in the USA to garner significant support was S 139, The Climate Stewardship Act of 2003. S139 did not pass, but it surprised many by gaining 43 votes in the Senate. It was introduced by Senators McCain (R, Arizona) and Lieberman (D, Connecticut) to impose a cap and trade approach to reduce green house gas (GHG) emissions. The phase I cap would limit annual emissions to the value from 2000. The phase II cap would limit emissions to the value from 1990.

The market would begin with 80% of the allowances allocated for free. The free percentage would decline to 20% over time. By the year 2025, 20% would be allocated for free and 80% of the allowances would be purchased at auction. S139 allowed for regulated industries to meet part of their obligations for emission reduction through offset contracts with unregulated industries and land owners. These contracts with unregulated business are called "offsets" because they reduce the regulated business's obligation to cut emissions or to buy allowances. Offsets were limited to15% in phase I, and 10% in phase II.

S 139 was the subject of a detailed study by the US Energy Information Administration.[18] The EIA (2003) study revealed that the electric power sector would lead the way in reducing CO2 emissions. The power sector would cut emissions far more strongly than other sectors and have allowances to sell to other sectors with less access to low cost reductions. The EIA analysis demonstrated that reduction in coal-fired generation would allow for the vast majority of the power sector response.

The EIA findings for the nation as a whole were confirmed in a WSU study of the western power system (Ford 2008). We found that the western system could cut CO2 emissions by 75%, a result similar to the EIA findings for the entire nation. The reduction in coal-fired generation accounted for the majority of the simulated response in the western system by 2025. The short-term response of the industry was dominated by "fuel-switching," the ability of the system to substitute gas-fired generation in combined cycle (CC) gas plants for generation from the coal-fired power plants.

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[18] The EIA reports are among the best available studies of carbon proposals. Other informative reports are available from the MIT research program on the science and policy of global change (MIT 2009).

Appendix E. Carbon Market Proposals Since 2003

A wide range of carbon market proposals have been introduced subsequent to S 139. An encouraging trend is the call for more ambitious caps on GHG emissions. As a general rule, the more recent proposals look further into the future and call for emissions to be lowered further below the values in 1990.[19] Three bills will reveal the trends in carbon proposals over the past seven years:

- S 2191: Climate Security Act of 2007 (Lieberman and Warner)
- HR 2454: American Clean Energy and Security Act of 2009 (Waxman and Markey)
- S 1733: The American Power Act (Kerry and Lieberman)

S 2191 was introduced by Lieberman and Warner with the same near-term goal as S139. The 2007 proposal extended the regulatory time frame to the year 2050 with a cap set at 70% below the emissions in 1990. The more ambitious goal is encouraging, but the regulated industries' obligations are reduced by an increased ability to sign offsetting contracts. S 2191 would allow up to 30% of the required reductions to be met by offsets, with half of the offsets permitted with business in foreign countries. S 2191 was the subject of an EIA (2008) study, and the findings confirmed the pattern from previous study of S 139. Specifically, the electric power sector would lead the way in cutting emissions, and the primary reduction would come from reduced use of coal-fired generation.

From a political stand point, the most successful carbon proposal could be HR 2454, the American Clean Energy and Security Act of 2009. The Waxman and Markey bill passed in the House of Representatives (219 votes in favor, 212 votes against) in June of 2009. The ACES is a long, complex proposal, around one thousand pages in length. It calls for cap and trade in allowances with ample provisions for offsets. The cap on emissions of regulated businesses calls for their emissions to be 80% below the 1990 values by the year 2050. However, the regulated businesses' obligations can be avoided by signing contracts with unregulated businesses in the USA and abroad. Indeed, a total of 2 billion MTCO2/year are permitted. The EIA (2009) analysis of HR 2454 shows that the vast majority of the emission reductions would come from offsets and the dominant form of emission reductions would be international offsets.[20]

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[19] The year 1990 has become a reference year for many proposals since it was selected for the Kyoto protocol. Many (but not all) proposals call for emissions reductions relative to the emissions in 1990. An ambitious goal (needed to cut emissions sufficiently to avoid dangerous anthropogenic interference with the climate system) would call for GHG emissions to be 80% below the 1990 value by the year 2050.

[20] HR 2454 calls for cumulative emission reductions of around 24 billion metric tons of CO2 equivalent (MTCO2e) over the interval from 2012 to 2030. The single largest contributor is international offsets. The EIA results (2009, Fig ES-1) show international offsets accounting for around half of the 24 billion MTCO2e in a simulation without banking. Their simulations with banking show reductions of around 37 billion MTCO2e over the same interval. But once again, international offsets are also estimated to provide around half of reductions. Offsets are complicated to design and difficult to verify, and their justification is often grounded in the status quo (ie, that currently unregulated sectors in the USA and in foreign countries will never progress toward adoption of a regulated cap.) There are many reasons to fear that offsets are not for real, especially when proposed in such massive amounts. The problems with offsets are obliquely acknowledged in HR 2454 with a 5:4 offsets ratio. (This would require a regulated business to contract for 5 MTCO2e of offsets for every 4 MTCO2e of obligations to be avoided.)

An important feature of HR2 454 is the creation of a strategic reserve of credits that would be used to enforce a ceiling on the price of allowances. Every year throughout the cap and trade program, a certain portion of this reserve account would be available for purchase by regulated businesses as a “safety valve” in case the price of emission allowances rises too high. The sale of reserve credits would limit the upward trend in price, and the administrator would then strive to refill the reserve with international offsets. The reserve proposal raises the question of whether the reserve is sufficiently large to enforce the price ceiling. The reserve proposal would allow regulated emissions to exceed the cap, but that excess would be countered by previously acquired offsets that were drawn from the reserve. The administrator would then refill the reserve through additional contracts for international offsets.

The most recent carbon proposal is S 1733, the American Power Act introduced by Kerry and Lieberman. At around one thousand pages, the APA rivals the ACES in length and complexity. The APA is an energy bill as well as a climate bill. The energy portion deals with issues ranging from nuclear energy development to offshore drilling for oil. The climate portion sets a goal for 83% reduction in regulated emissions by the year 2050.[21] Offsets are an important part of the APA, but not as important as in the ACES.[22] Like the ACES, the APA provides cost containment with a price ceiling to be enforced with a strategic reserve.

In my view, the most encouraging feature of the APA is the creation of a Universal Trust Fund in the year 2026. The fund would collect the revenues from the growing fraction of allowances sold at auction. By 2035, around 78% of allowances would be sold at auction with the revenues feeding into the trust fund. These funds would then be paid to American households on a per capita basis to be designed by the Treasury Department. The refund idea is often called *Cap and Dividend*. The *cap* refers to annual limits on the CO2 emissions that would be sold at auction; the *dividend* refers to the direct refund of a large fraction of the auction revenues to the American people. The dividend feature of the APA is encouraging. Unfortunately, it is not scheduled to begin until 2026 and not likely to deliver major dividends until the year 2035. A far better approach is to implement cap and dividend from the outset of the newly created market.

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[21] The 83% goal in the APA is measured relative to emissions in 2005, not the emissions in 1990. The emissions cap would start in 2013 and apply to electricity and transportation, sectors which account for around two-thirds of domestic emissions. (The refineries face a somewhat different price setting mechanism than other sectors, a provision said to be needed because of the strategic importance of the refinery industry.) Industrial emissions would be added later, building the coverage to around 85%. The remaining 15% of US emissions are the treated separately from the cap and trade proposal.

[22] The APA limit on offsets is 1billion MTCO2/year, still a huge amount, but half of the limit set in the ACES.

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