The Marginal Effects of the Price for Carbon Dioxide: Quantifying the Effects on the Market for Electric Generation in Florida

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Abstract

Greater emphasis on public policy aimed at internalizing the societal cost of carbon dioxide emissions leads to more questions about the economic impacts of that policy. The United States Congressional Budget Office, Environmental Protection Agency, and Department of Energy's Energy Information Administration have all recently released their estimates of the macro-economic impact of various proposals for environmental legislation. The focus of these studies is on the level of certain output variables such as the level of carbon dioxide emissions, the cost of emissions allowances, and the broad impact of increased electricity prices, rather than microeconomic or marginal effects of policy change.

In cooperation with the State of Florida's Department of Environmental Protection, we have constructed a model to simulate the dispatch of electric generating units to serve electric load in the state of Florida. In this paper, we present the results of an analysis of

the units used to generate electricity in Florida, and the marginal effects of carbon dioxide emissions prices on their dispatch. Using the operating characteristics of Florida's generating units, and a least-cost economic dispatch model, we analyze the effects that changes in emissions prices have on Florida's level of carbon dioxide emissions, the amounts (and types) of fuel consumed for electric generation, and the wholesale cost to generate electricity. We find that at relatively low carbon prices emissions levels decrease, but that coal usage actually increases in the short term as fuel sources such as petroleum coke and fuel oil are displaced. Once this initial reduction has been achieved, further increases in carbon prices may do little to decrease emissions until a 'critical point' has been achieved and coal can be displaced by natural gas. Our results suggest that the marginal effects of carbon prices will vary greatly with the carbon price level, and the fundamental characteristics of the market.

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Introduction

In July of 2007, Florida Governor Charlie Crist hosted the historic "Serve to Preserve: A Florida Summit on Global Climate Change," in Miami. This summit brought business, government, science, and stakeholder leaders together to discuss the effects of climate change on Florida and the nation. On the second day of the summit, July 13, the Governor signed three Executive Orders to shape Florida's climate policy. Order 07-126 mandated a 10% reduction of greenhouse gas emissions from state government by 2012, 25% by 2017, and 40% by 2025. Order 07-127 mandated a reduction of greenhouse gas emissions from the state of Florida to 2000 levels by 2017, 1990 levels by 2025, and 20% of 1990 levels by 2050. Finally, Order 07-128 established the Florida Governor's Action Team on Energy and Climate Change and charged the team with the development of a comprehensive Energy and Climate Change Action Plan.

On June 25, 2008, Florida House Bill 7135 was signed into law by Governor Crist, creating Florida Statute 403.44 which states: "The Legislature finds it is in the best interest of the state to document, to the greatest extent practicable, greenhouse gas emissions and to pursue a market-based emissions abatement program, such as cap and trade, to address greenhouse gas emissions reductions." The initial focus of the state government is to place a cap on the amount of carbon dioxide emitted by the electric power generation sector.

Studies on the economic impact of CO_2 pricing on the market for electric generation have been performed for the ERCOT region in Texas[1], as well as the PJM region in the Northeastern United States[2]. Examining the conclusion for those two studies shows how the relative carbon intensity of the electric generation fleet can have a marked impact on the economic effects of CO_2 pricing. Therefore, a distinct model for the state of Florida is necessary to measure that impact.

Characteristics of Emissions Caps

A cap is a regulatory device used to limit the production of certain substances, often byproducts of the production of other goods. In the case of Florida Statute 403.44, the target of the cap is the carbon dioxide that is produced as a by-product of the generation of electricity. Emissions caps can be one of two types, either restrictive or nonrestrictive. A cap that is nonrestrictive is one where the cap does not affect current production of electricity. That is, if an emissions cap is placed at a level at or above the unconstrained level of emissions produced by the electric generation sector, then the cap will have no affect on the market as "business as usual" is allowed to continue. If, however, a cap is placed at a level below the level of emissions produced in an unconstrained market, then this will impose an additional constraint on the generating system. This additional constraint will necessitate a cost. That is, if a firm is considered, without any constraint, to be producing goods at the least possible cost, then applying an additional constraint will necessarily lead to increased costs. In the case of an emissions cap, the monetization of this constraint is a price on the emission of carbon dioxide. So an imposed emissions

[1] http://www.ercot.com/content/news/presentations/2009/Carbon_Study_Report.pdf
[2] http://www.pjm.com/documents/~/media/documents/reports/20090127-carbon-emissions-whitepaper.ashx

limit at or above the “business as usual” or unconstrained case implies an emissions price of zero. As the emissions cap decreases below the unconstrained case, the emissions price increases.

The strategies to reduce emissions from the electric generation sector are limited. In the short term, the generators can adjust the types of fuels that they use, known as fuel-switching, or reduce the amount of electricity that they produce. In the long term, the generators options expand to strategies such as: improving the thermal efficiency of existing power plants (and thus reduce fuel consumption), construction of new power plants that produce electricity while emitting less (or no) carbon dioxide, or developing and exploiting technologies that captures a portion of the carbon dioxide emitted. An electric generation unit-level economic dispatch model can be used to simulate the effects that the price of emissions (or, similarly, an emissions cap) has on the electricity sector.

Model of Economic Dispatch

The problem of least-cost economic dispatch of a group of electric generating units is to minimize the aggregate costs required to provide the amount of electricity demanded by end-users in each hour. The costs to produce this electricity will be driven by the type of generating unit, its operating efficiency, the variable costs required to operate and maintain the unit, and the price of its fuel. At its most basic, the problem can be stated:

$$\min_{G} \sum_{i=1}^{n} G_i \{[(CO2 * Emit\$) + Fuel\$] * HeatRate + O\&M\$\}$$

subject to the constraints:

$$\sum G_i \geq L_t$$

$$G_i \leq C_i \; \forall i$$

where:

G_i	MWh generated by the *i*th generating unit in hour *t*
C_i	Maximum hourly generating capacity in MWh of the *i*th generating unit.
L_t	Electric load in hour *t*
CO2	Tons of CO_2 emitted per MMBtu of fuel consumed
Emit$	Emissions cost per ton of CO_2
Fuel$	Cost of fuel per MMBtu consumed
HeatRate	Heat rate (measure of thermal efficiency of the plant) in MMBtu/MWh
O&M$	Operation and maintenance expenses in $/MWh

The variable costs are the costs that increase as production increases, and decrease as production decreases. The differences between fixed and variable costs are shown below in Table 1.

Generating Unit Cost Classification		
Classification	**Cost**	**Description**
Fixed Costs	Capital Costs	Costs required to build the power plant
	Fixed Operations and Maintenance Expenses	Costs to operate and maintain the plant that do not vary with the level of production, such as annual maintenance costs and some salaries
Variable Costs	Variable Operations and Maintenance Expenses	Costs to operate and maintain the plant that vary with the level of production, such as more regular maintenance and equipment costs, and some salaries
	Fuel	Costs associated with procuring, handling, transferring, or delivering fuel to the plant

	Emissions	Costs associated with emission of carbon dioxide

Table 1. Fixed and Variable Costs

Without a price for emitting carbon dioxide, the *Emit$* variable is zero and the amount of CO2 emitted by that generating unit does not enter the dispatch equation. With a positive value for *Emit$*, the total cost of emissions is driven by the operating efficiency of the generating unit and by the type of fuel, as some generating fuels emit relatively more carbon dioxide when burned. The fuels that emit relatively more carbon dioxide when burned, such as coal and petroleum coke, are often referred to as “dirty” fuels, and the fuels that emit relatively less, such as natural gas, are referred to as “clean” fuels. Therefore, the price of emissions may necessitate the switch from a dirtier generating fuel to a cleaner one by an individual generator capable of burning more than one type of fuel, or may lead to a generator that burns a dirtier fuel being replaced by a generator that burns a cleaner fuel.

The calculation of the optimum is made in two stages. First, the hourly cost is calculated for each available generating unit. For units with the capability to burn different fuels, the cost and emissions rate of each fuel are considered and the least-cost alternative is selected. Second, all of the generating units are ordered from lowest cost to highest, and the units with the lowest hourly costs are dispatched until the hourly electric loads are met.

Data Sources

Data for individual generating units, such as summer and winter generating capacity, prime mover, and fuel sources, were acquired from the United States Department of

Energy's Energy Information Administration (EIA) Form 860 (Annual Electric Generator Report) and Form 861 (Annual Electric Power Industry Database) databases. Data on generating unit operating efficiency, such as heat rate, were acquired from EIA Form 423 (Monthly Cost and Quality of Fuels for Electric Plants Data) filings from each of the utilities that are required to file the report. Some plant level operating data, such as variable operating and maintenance expenses, were acquired from utility responses on Form 1 (Annual Report of Major Electric Utility) to the Federal Energy Regulatory Commission (FERC). Other operating and contract data, as well as long term load forecasts, were acquired from the Regional Load and Resource Plan published by the Florida Reliability Coordinating Council. Actual hourly loads were acquired from utility responses on Form 714 (Annual Electric Control and Planning Area Report) to the FERC.

Data for projected generating units were acquired from the Regional Load and Resource Plan. Projected fuel prices are taken from the 2009 Annual Energy Outlook published by the EIA. The Annual Energy Outlook Reference Case is used for the base scenario, and high and low price scenarios are developed from the High and Low Price cases.

Model Operation

Within each month of the model run, the model first determines the order of dispatch in which the generating units will be dispatched to meet electric load, often called the generation stack, and then dispatches the generation stack against the monthly load shape on an hourly basis. When ordering the generation stack, the model considers the fuel cost, variable operation and maintenance expenses, unit efficiency, and emissions price. The model then selects the least-cost fuel source for any unit with the capability to switch fuels.

When dispatching each unit, the model discounts each unit's production capacity by the unit's availability factor. This availability factor reflects distinct operating characteristics of different types of generating units. Electrical generation in different types of units may or may not be controlled by the operator of the unit. For a unit that burns fossil fuels, for example, if the power plant is running and has fuel available, it will generate electricity. These types of units are also called dispatchable units. For a unit that relies on the sun or the wind to generate electricity, however, that power plant will not produce electricity if the sun is not shining or the wind is not blowing. These types of units are also called nondispatchable units.

For nondispatchable units, then, the availability factor reflects the amount of time that the sun is shining or the wind is blowing. For dispatchable units, this availability factor reflects the times when the unit is available to generate. The unit may be unavailable due to either a planned or unplanned outage. Ideally, two factors would be used to reflect unit availability. The first would reflect planned unit outages, most commonly for routine maintenance. The second factor would reflect unplanned, or forced, outages; the instances where a unit breaks down unexpectedly. However, individual unit outage schedules are difficult to acquire, are dynamic, and can be indeterminate for extended timeframes. To ameliorate these modeling limitations, a discount methodology using an availability factor, often called a "derate" methodology, is employed.

Model Output

During execution, the model tracks the energy production for each unit, as well as the units of fuel burned, the total dispatch costs, and the carbon emissions. These output variables can be aggregated by utility, type of plant, fuel type, and by custom classifications.

The model output consists of matched sets of emissions prices, emissions levels, and the amounts of each generating fuel burned for each model year. Therefore, each level of emissions will imply a price of emissions and a fuel mix, and vice versa. In that manner, we can find the price of emissions and mixture of generating fuels that correspond to each level of carbon dioxide emissions, for each compliance year in the analysis. Further, we can also compute the effects of different levels of emissions (and the resulting emissions prices) to allow the computation of the marginal effects of the emissions policy.

We ran the model for the years 2010-2024, varying the CO_2 price from $0 to $100 per ton. We looked at how several output variables behave both over time and across the spectrum of CO_2 prices. The first variable was the change associated with the average variable cost component of electricity production.

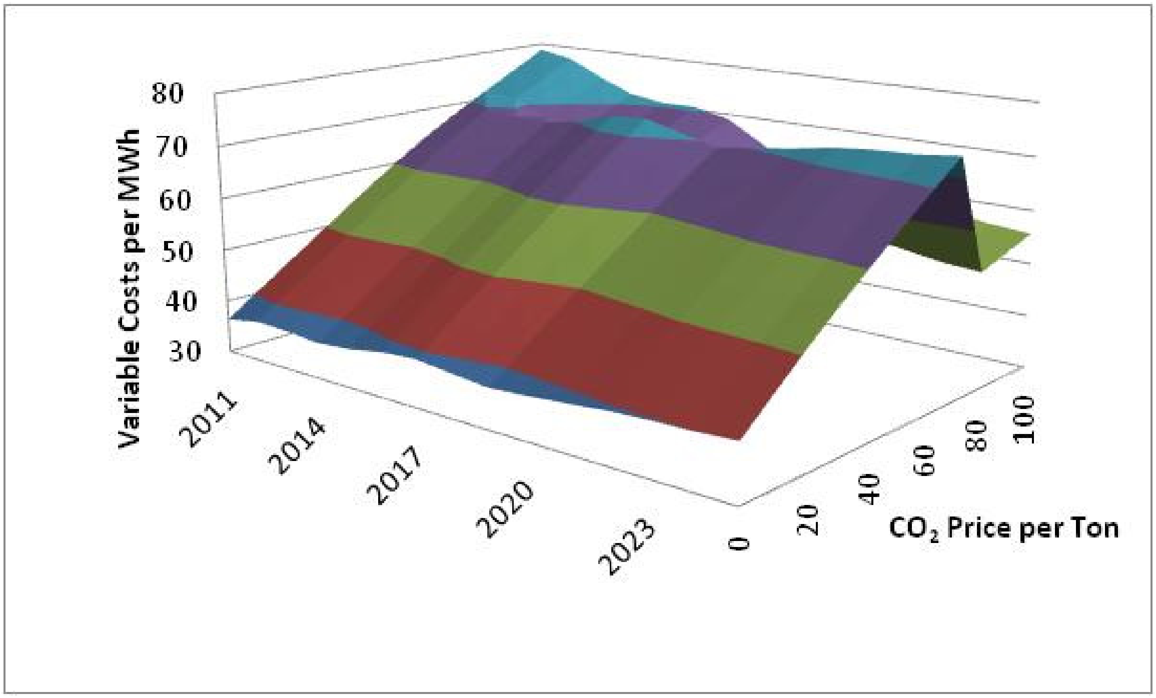

Figure 1. Incremental cost of electricity under increasing emissions prices

Figure 1 shows the variable cost of electricity over time, under increasing emissions prices. While the relationship does change slightly as we look further into the future, the relationship between emissions prices and incremental cost is fairly stable, as a $1 increase in emissions prices tends to raise the price of electricity in Florida by just under 55¢ per MWh, or about $6.60 per year for a family that uses 1000 kWh per month, and this effect stays relatively constant for emissions prices from $1 to $100/ton. The steep decline at $90, in the later years, is the effect of new natural gas-fired generation being displaced by new biomass-fired generation. This causes a decrease in variable costs, with a corresponding increase in the level of fixed costs.

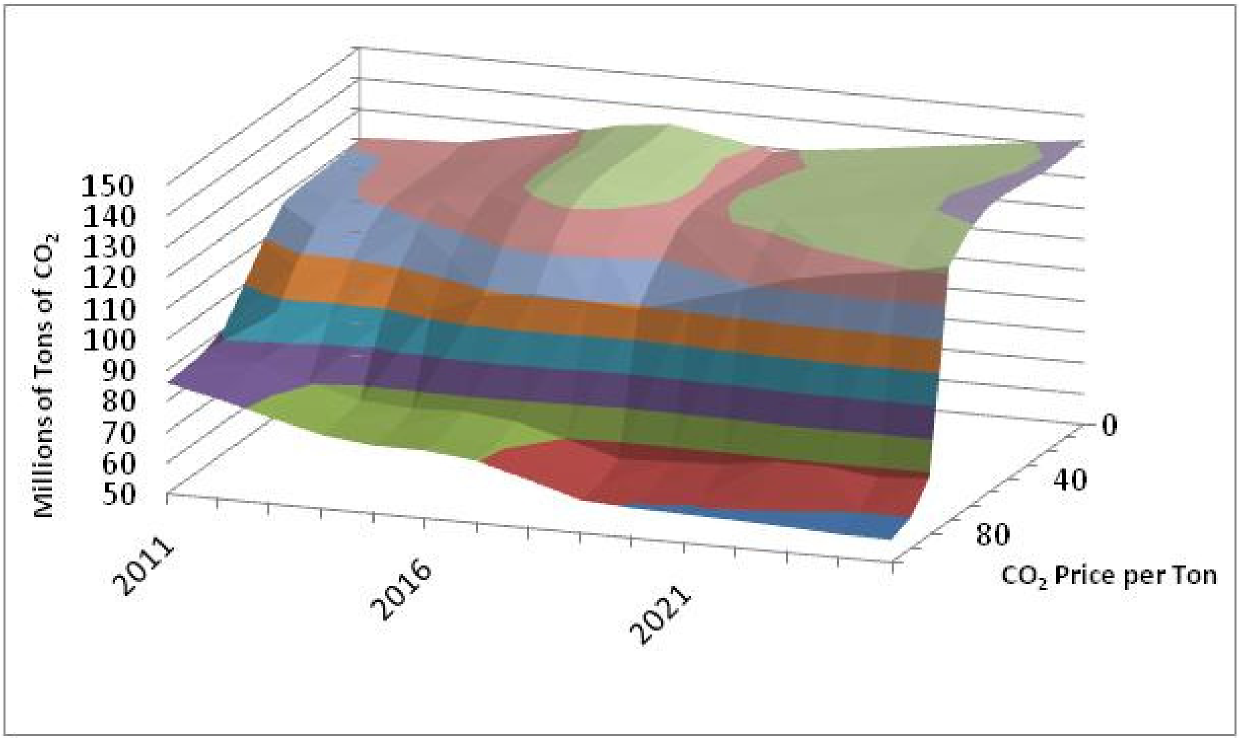

Figure 2. Emissions levels through time under different emissions prices

Figure 2 illustrates the effects of simulating various carbon dioxide emissions prices on the emissions of the electric generating sector. Emissions levels are initially reduced 2-3% under relatively low emissions prices. This is primarily due to the displacement of petroleum coke as a generating fuel in Florida. However, emissions levels then reach a plateau, whose magnitude varies, during which increasing the price of emissions has relatively little effect on overall emissions levels. Once emissions prices exceed a critical value, however, a rapid decline in emissions levels occurs. This decline in emissions occurs at $45 per ton in the near term, as coal-fired generation is displaced by natural gas. Another drop is evident at $90 per ton, in the later years, as new biomass generation displaces new natural gas generation.

Knowledge of the shape of this emissions surface is important for two major policy questions. First, it allows us to see the effect that increasing the price of CO_2 has on emissions levels. If the aim of environmental policy is to reduce emissions in the most cost-effective manner, it is important to know the marginal reduction associated with the price of emissions. In this particular instance, the difference in emissions reduction from a $10 emissions price and a $40 emissions price is very small. Yet, from Figure 1, we can see that the difference in realized wholesale prices will be about $15/MWh higher with a $40 emissions price than a $10 emissions price. Whether the relatively small reduction in emissions is worth this extra cost is an important policy decision. Second, this emissions surface can allow the evaluation of the different paths that can be used to achieve emissions milestones. For example, environmental policy may state an emissions goal of a 25% reduction in emissions by 2025, but no interim goals. This 25% reduction can be achieved with a gradually declining emissions cap over many years, or an emissions cap that is imposed suddenly in 2025. Either way, the understanding of the interaction between CO_2 price and CO_2 emissions cap, as well as the incentives necessary to influence producer behavior is critical to the ultimate success of the policy.

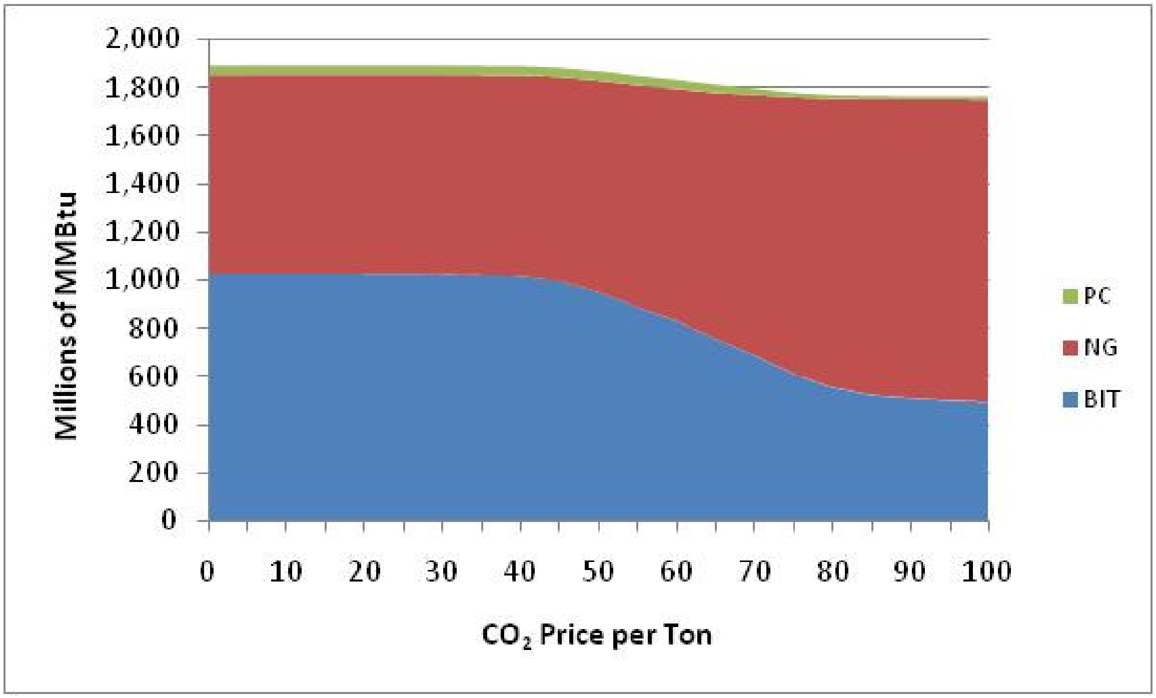

Figure 3. Fuel usage in 2012 under different emissions prices

Figure 3 illustrates the amount of coal, natural gas, and petroleum coke burned under various carbon prices. Initial reductions in emissions levels occur as petroleum coke, a relatively dirty fuel is displaced. However, petroleum coke is only partially displaced with natural gas, a relatively clean fuel. Most of the petroleum coke is displaced with increased coal usage. Once the petroleum coke has been fully displaced, further increases in emissions prices do little to reduce emissions, as prices have not increased to the levels necessary for coal to be displaced by natural gas. Once that level is reached, however, emissions levels decrease rapidly.

This result is somewhat counter-intuitive, as it is commonly assumed that an increase in the price of emitting carbon dioxide will result in the decreased use of coal. However, this intuition may not hold in all markets, and may not be consistent across all market conditions. In Florida, for example, generators burn fuels that are somewhat dirtier than coal, so these fuels are the first to be displaced. Further, the only fuels capable of displacing coal in the short term are nuclear and natural gas. Nuclear power plants have even lower operating costs than coal plants and are typically utilized as much as they can be. As such, the only short-term fuel capable of displacing coal is natural gas. However, coal is much cheaper than natural gas, so the additional cost due to emissions has to reach a sufficient level for natural gas generation to begin to displace coal. This is illustrated in Figure 3 as an emissions price of approximately $45.

Conclusions

The marginal effects of emissions prices are one of the questions raised with the greater emphasis on public policy aimed at internalizing the societal cost of carbon dioxide emissions. We present the results of an analysis of the units used to generate electricity in Florida and the marginal effects of carbon prices on their dispatch. Using the operating characteristics of Florida's generating units, and a least-cost economic dispatch model, we analyze the effects that various emissions prices (and their concurrent emissions levels) have on Florida's level of carbon dioxide emissions and the amounts of fuel consumed for electric generation. We find that at relatively low emissions prices emissions levels decrease, but that coal usage actually increases as fuel sources such as petroleum coke and fuel oil are displaced. Once this initial reduction has been achieved, further increases in carbon prices may do little to decrease emissions until a "critical point" has been achieved, and coal can be displaced by natural gas. These counter-intuitive results suggest that the marginal effects of emissions prices may vary greatly with the emissions price level and the fundamental characteristics of the market.

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