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ENVIRONMENTAL AND ECONOMIC IMPACTS OF A CARBON TAX: AN APPLICATION OF THE LONG ISLAND MARKAL MODEL

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ABSTRACT: *The local impact of a regional or national policy change in regards to carbon emissions is a problem which needs to be addressed. It is likely that new greenhouse gas reduction legislation will be more ubiquitous and stringent than predecessors and one such mechanism may be a carbon tax. This paper explores the impacts of two different carbon tax policies ($10/ton flat tax and $10/ton in 2010, increasing $10/year for at least the next 10 years [$100 tax] and held constant beyond that point, on Long Island, New York. Using the MARKAL model to simulate the performance of the Long Island electricity generating sector, we find that the initial introduction of a flat $10/ton carbon tax will lead to a rapid phase-out of older (and dirtier)electric generating stations. We find that the additional impact of an increasing carbon tax rate (from $10/ton to a maximum of $100/ton) is minimal.*

KEY WORDS: *energy modeling, climate change, greenhouse gas, carbon tax, MARKAL*

INTRODUCTION

The demand for energy is intertwined with many of our most pressing environmental threats. Among these threats, the risk of climate change is perhaps the one that looms largest. Other environmental issues associated with our energy systems have an impact at local or regional scales, including acidification and the dispersion of metals from mining and burning fossil fuels. (Johansson and Lundqvist, 1999) Although there are a number of sources of criteria air pollutants (ozone, particulate matter, carbon monoxide, nitrogen oxides and sulfur dioxide) and greenhouse gases (carbon dioxide, methane, nitrous oxide and fluorinated gases), electric power plants are regarded as the largest single point source. (Jeong, et al., 2008) Although the magnitude of the anthropogenic contribution to global warming is subject to debate, the basic relationship between the combustion of fossil fuels, the atmospheric concentration of carbon dioxide, and mean global temperature has been understood since Arrhenius in 1896. Approximately 29 billion tons of carbon dioxide is added to the atmosphere each year through human activity, of which 23 billion tons is the result of fossil fuel burning and industrial activity. (Jean-Baptiste and Ducroux, 2003) Approximately two-thirds of U.S. fossil fuels (coal, petroleum and natural gas) are used by the U.S. electricity sector, and this share is growing over time (Nagurney and Woolley, 2006).

As our technology advances, our need for energy seems to expand at an even greater rate. This is caused by increases in everything from vehicles to electrical appliances and tools. But simply building power plants and generators may not solve the problem of supplying electricity efficiently; it may actually cause more of a problem. (Teresko, 2001) Although there are numerous greenhouse gases (GHGs), carbon dioxide is generally focused upon because it is a major byproduct of fossil fuel combustion, from which the majority of our electricity generation is derived. The bulk of the other GHGs are related to the combustion of fossil fuels. (Gielen and Kram, 2000) Further, it has been noted that CO_2 emissions reductions simultaneously reduces other criteria pollutants (SO_2, NO_x, PM_{10}), as has been seen in Shanghai China. (Chen et. al., 2001) The impact on climate change of methane nitrous oxide, and fluorinated gases are comparable in magnitude to the impacts attributable to carbon dioxide. (Hansen and Sato, 2004; IPPC, 2007) Since the non-CO_2 emissions are falling below the IPCCs scenarios, the current focus of climate change policy is on emissions of carbon dioxide (Hansen, et. al., 2008).

Global increases in carbon dioxide are being seen at a rate that many models predict can lead to a temperature increase equal in magnitude to the cooling experienced during the last Ice Age. This type of increase may be responsible for the bleaching of coral reefs, cause a shutdown of the thermohaline circulation in the Atlantic Ocean, and lead to a rise of sea level (Hoffert et al, 2002).

The United Nations, at the Earth Summit held in Rio in 1992, called for a worldwide stabilization of greenhouse gases as to avoid, “dangerous anthropogenic interference with the climate system.” (United Nations Framework Convention, 1992) The most recent report of the Intergovernmental Panel on Climate Change (IPCC) (Fourth Assessment Report: Climate Change, 2007) concluded: 1, warming of the climate is unequivocal; 2, warming observed since the mid-20th century is likely associated to anthropogenic activity; 3, the probability of this warming being a natural event alone is less than 5%; and 4, the past, current, and future anthropogenic CO2 emissions will continue to contribute to warming for more than a millennium. With rapid climate change impacting Earth systems within a century or less (Hansen, et. al., 2007) there is growing realization that an Earth energy balance no longer exists and further warming lies down the road. (Hansen, et al, 2005) Many politicians, scientists and even industrial leaders have called for action. Rex Tillersin, CEO of Exxon Mobil has called on Congress to enact a “lucient” and efficient carbon tax (Gold and Talley, 2009).

A wide range of proposals to impose mandatory caps on U.S. greenhouse gas emissions have been introduced in the U.S. Congress. (Paltselv et al., 2007) Although the prospects for action at the national level are uncertain, other programs have been introduced by state governments, acting individually and in concert with their neighbors. Examples of these actions include the Regional Greenhouse Gas Initiative (RGGI, 2009) and Western Regional Climate Action Initiative (WRCAI). Pew Center (2009) provides a detailed inventory of state initiatives. Other initiatives have been implemented by local governments (see Linky, et al., 2008). It seems that climate change programs implemented at the regional, state and local levels will create pressure for action by the U.S. Congress and federal agencies. Jason Grumet, an energy expert and head of the Bipartisan Policy Center, recently stated that “setting a price on carbon in the power sector is the most significant opportunity we have to achieve domestic greenhouse gas reductions.” (Leonhardt, 2010) Recently, the United Nations Climate Change Conference (2009, COP15) has concluded with mixed outcomes. A Copenhagen Accord has been established which seeks to enact a Copenhagen Green Climate Fund. This developed nation funded 10 billion-dollars-a-year, three-year program starting in 2010 will fund developing nations' projects to deal with drought, floods and other impacts of climate change, as well as develop clean energy. It also set a longer term "goal" of providing 100 billion dollars a year by 2020. The Accord also seeks to cap temperature rise to 2°C and reduce CO2 emissions. In 2011, the Environmental Protection Agency (EPA) began regulating carbon emissions under the provisions of the Clean Air Act. On December 30, 2010, the U.S. EPA established an implementation strategy for the issuance of carbon permits. (USEPA, 2010). Legislation to suspend EPA authority to regulate greenhouse gases has been introduced in the U.S. Senate (S. 231, 2011).

GREENHOUSE GAS MITIGATION POLICIES

There are a number of environmental policies that can be enacted, and have been proposed, to reduce pollution levels, including carbon dioxide emissions. Command and Control (CAC) instruments include emissions restrictions and design standards. Examples of CAC include catalytic converters on cars and scrubbers on power plants. Permit policies may be implemented whereby the right to pollute is established with permits that are either handed out to firms at a rate equal to some fraction of a previous year’s emission level or sold by the government at auction. These permits can then be sold or traded at some market rate. (Fullerton, 2001) Examples of these trading systems include the U.S. SO2 trading program, which has been very successful and has had a significant impact on environmental quality and the E.U. European Trading System for CO2 which has seen volatility in market price and limited emissions impact. (Anthoff and Hahn, 2009) While many have proposed carbon taxes (Baranzini et al, 2000), others have called for “green” credits or subsidies. (Painuly, 2001; Schaeffer, et al, 1999) These policy instruments are Pigouvian solutions. (Pigou, 1932) Pigouvian solutions are taxes levied against activities with negative externalities, at a rate equal to the cost of these externalities. (Baumol, 1972) Unfortunately, subsidies such as those provided to farmers in the U.S. lead to a market which is no longer competitive and pays firms to “cut production, raise price, and make profits.” There are no true Pigouvian taxes on pollution in the U.S. There are environmental taxes on petroleum, chemical feed stocks, ozone depleting chemicals, and motor fuels, but these fund environmental programs such as Superfund and Leaky Underground Storage Tank fund, and are not meant to directly discourage pollution (Fullerton, 2001).

A carbon tax on carbon dioxide emissions would be a powerful policy mechanism that could address market failures, such as hidden externality costs. (Wu, et al., 2006) Further, it would be easy to implement, as carbon content of fossil fuels used are easy to calculate and trace. (Fullerton, 2001) The burden of such a tax would be distributed over all areas (residential, commercial, industrial, etc.) and will help environmental protection. (Pehlivan and Demirbas, 2008) By raising the variable costs of producing electricity from fossil fuels, an incentive will be established to shift towards cleaner technologies. (Green, 2008) Taxes, by their nature, raise revenues.

Becker and Mulligan (2003) show that governments who find more revenue tend to spend it rather than lower other taxes. It is possible, however, to create a revenue-neutral carbon tax by using the revenues it generates to offset other taxes. (Metcalf, 2009). Parry et al. (1999) found that a carbon tax, which "cut distorting labor tax rates", was less costly than a carbon permit system. If the policy is carefully crafted, the revenue from a carbon tax can offset other taxes and improve economic efficiency. For these reasons a carbon tax will be the scenario chosen for the model.

The literature and established tax systems used world-wide may be used as a beginning to understand the impacts of these taxes. There are many estimates of the social cost of carbon (net benefits and costs). Peer-reviewed estimates of these costs have an average value of $12 per ton of carbon dioxide with a large range around this mean. In a survey of 100 estimates, the values ran from $ 3 per ton of carbon dioxide up to $95 per ton of carbon dioxide. (Tol, 2005) According to the Carbon Tax Center (a nonprofit started by economist Charles Komanoff (2008) and attorney Dan Rosenblum, 88 estimates of the marginal costs of carbon dioxide from 22 published studies were analyzed. The mode cost of carbon dioxide was determined to be $5/tC, the mean $104/tC, and the 95 percentile $446/tC. When incorporating assumptions about aggregation and discounting, the marginal costs of carbon dioxide emissions is unlikely to exceed $50/tC, and is probably much smaller.

William Nordhaus, a Yale economist, in *A Question of Balance: Weighing the Options on Global Warming Policies* (2008) concludes that a carbon tax starting at $7.40/ton of CO2 is optimal, so long as it increases by 2-3% a year after inflation until 2050, with even steeper increases after that. Metcalf (2007) has called for an optimal CO2 tax rate of $16.60 with no annual adjustments. Shapiro, et al (2008) has called for an optimal rate of $15 per ton of carbon dioxide, with an increase of $2/ton each year. The Carbon Tax Center has proposed a $10/ton tax increasing $10/year for at least the next 10 years ($100 tax) and held constant, or more aggressively continued to increase for 20 years ($200 tax).

On January 1, 1991, Sweden enacted a carbon tax, $100 per ton, on the use of fossil fuels. In this case the tax was not equally distributed. For political reasons, industrial users paid between a quarter and half the rate while certain high-energy industries (mining, manufacturing and the pulp and paper industry) were exempted from these taxes. In 1997 the rate was raised to $150 per ton of CO2 released. (Brannlund, 1999; Brannlund and Gren, 1999; Ekins, 1996) This type of treatment may not sit well in this country, but provides another example of the flexibility of a carbon tax.

Numerous studies have been carried out in regards to the impacts of carbon taxes at the national level. Jeong, el al (2008) investigated a carbon tax on Korea's utilities comparing coal and LNG in the presence of a carbon tax. Masui, et al (2006) investigated a carbon tax in Japan, as a mechanism to achieve a 2% CO2 reduction of 1990 emissions, in order to abide by Kyoto targets. This study aims to determine the local impacts of two proposed carbon tax policies in an "isolated" region (Long Island, NY) with an aging electric utility infrastructure.

THE MARKAL MODEL: A TOOL FOR POLICY ANALYSIS

A commonly used optimization model for energy systems is MARKAL (MARket Allocation). This is a bottom up linear programming model that was conceived by the Energy Technology Systems Analysis Programme of the International Energy Agency. The model shows the supply and demand sides of the energy system. MARKAL has been used by over 50 countries and over 110 institutions. MARKAL is able to address the interactions and competition between many energy forms and technologies, from conventional such as oil and natural gas to renewable such as, wind and solar. Some uses of MARKAL include: to identify least-cost energy systems, to identify cost-effective responses to restrictions on emissions**,** to evaluate new technologies and priorities for R&D, to evaluate the effects of regulations, taxes, and subsidies, and to project inventories of greenhouse gas emissions (MARKAL, 2001)

There are several extensions based on the standard MARKAL model: MARKAL-MACRO (macro-economic model), MARKAL-MICRO (micro-economic model), MARKAL with multiple regions (includes emissions permit trading), and MARKAL with materials flow (in addition to energy flows this includes recycling of materials. The MARKAL model is particularly useful to answer energy policy and planning questions. One such application is the least cost solution for meeting energy demands subject to limits to emissions such as CO2 and/or other greenhouse gases. MARKAL has been widely applied to studies of the energy and environmental impacts of climate change. (Zhang and Folmer, 1998; Koen, 2004; Rafaj and Kypreos 2007; Sukla et al, 2008)

THE LONG ISLAND MARKAL MODEL: METHODS AND RESULTS

A 2005 baseline Long Island MARKAL model was established in order to investigate the impacts of policy changes on Long Islands electricity generating future (see Lee et al, 2009 for details of baseline). A basic reference energy system (RES) showing energy flows from supply to end use, can be found in Figure 1. In 2005, the total installed generating capacity available to Long Island Power Authority (LIPA) was 4,983 MW to meet an average load requirement of 4,607 MW. The New York Independent System Operator (NYISO) that oversees New York State's power transmission system and administers New York State's wholesale electricity market mandates that 95% of Long Island's demand for electricity must be met from on-island sources. NYISO contends that New York's electric system will be stretched to and beyond its capacity with increasing demand in the near future, as a result of capacity constraints and transmission bottlenecks. This has created an imperative that additional capacity should be developed and energy efficiency (demand side management) improvements are made on Long Island to meets its future demand in power and electricity. The remaining 5% and peak load are met by off island sources. Neighboring systems from which LIPA has contractual agreements to purchase power include: New York Power Authority (50 MW), Nine Mile Point 2 (200 MW), Cross Sound Cable (330 MW), and Neptune Cable (660 MW). In terms of fuel use for generation, natural gas has gone from less than half of the dual fuel power plant market in the 1970s to around 80% in recent years. In fact, fuel oil consumption for power plants dropped over 90% in the last two decades. New York has become increasingly reliant on natural gas. Almost all new generation facilities proposed on Long Island, aside from some renewable (wind and solar) projects, are natural gas fired because of its efficiency and environmental qualities. In 2005, the total electricity sales on Long Island amounted to over 20 billion KWh. The residential sector was the largest end-user, consuming about 50% of this total. The commercial and industrial sectors combined accounted for the remaining 50% of the electricity sales, with a small amount used by public authorities (e.g., street lighting).

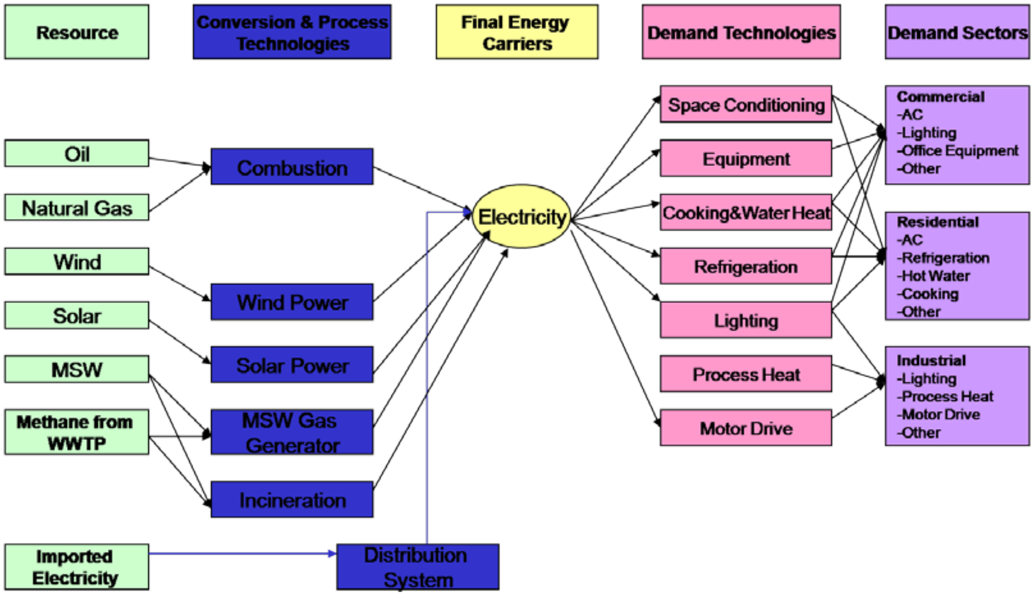

Figure 1: Simplified Long Island Reference Energy System**.**

Using the baseline LI MARKAL, two possible carbon tax scenarios were established. The first was a $10 per ton CO2 flat tax that initiates in 2010. The second was a tax that begins at $10 per ton in 2010, increasing $10/year for at least the next 10 years ($100 tax) and held constant beyond. Though there is much discussion in the literature regarding types of taxes which should be enacted, there is little discussion in regards to how local/regional areas are impacted by these federal decisions.

The impacts of carbon taxes are generally discussed at national levels, as they would be implemented at that scale. Clearly there is a need to understand the impacts at the local level. Table 1 and Figure 2 provide an indexed cost for years 2005 (base year) through 2050, and a summation of those years indexed costs. Table 2 and Figure 3 provide the indexed total CO_2 emissions for 2005 (base year) through 2050, and a summation of those years indexed emissions. These values are indexed to the 2005 base year as considering the results of modeling analysis it is most useful to focus on the difference between scenarios than on the absolute numbers of a single scenario. It is the differences that form a basis for analyzing policy changes and not absolute numbers.

Table 1: Indexed Total Undiscounted System Cost

Taxes	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	Sum
Base	100.00	240.18	105.77	105.51	231.45	113.93	128.76	241.39	150.25	119.85	1537.09
Flat	100.00	240.14	105.73	105.48	231.43	112.93	124.28	237.96	130.61	101.17	1489.73
Incremental	100.00	240.14	105.73	105.48	231.43	113.64	128.93	241.30	150.24	119.85	1536.74

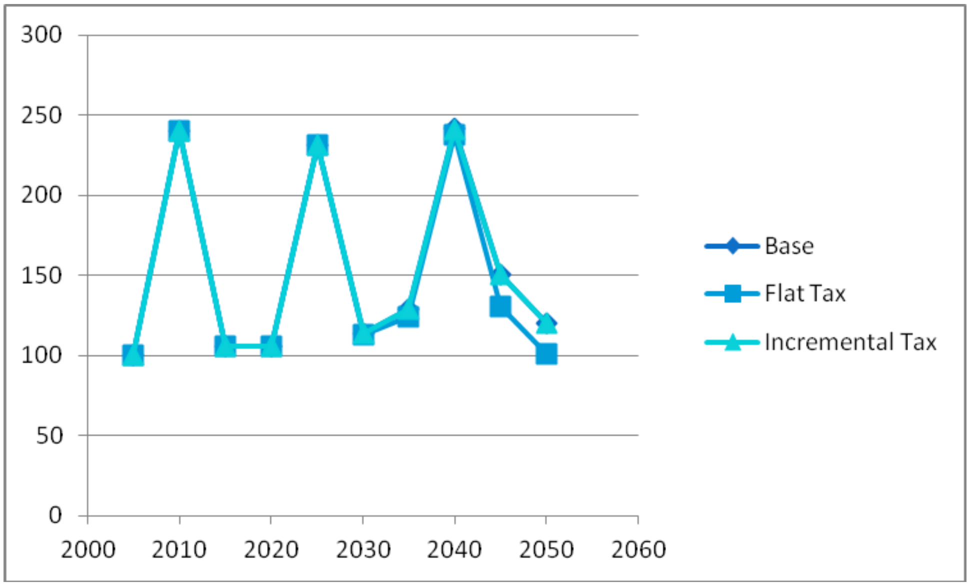

Figure 2: Indexed Total Undiscounted System Cost

Table 2: Indexed Total CO2 Emissions

Taxes	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	Sum
Base	100.00	102.93	104.88	105.61	107.55	105.11	94.17	94.53	68.15	71.15	954.08
Flat	100.00	95.57	98.38	99.71	102.15	97.93	81.99	79.37	67.57	70.57	893.24
Incremental	100.00	95.57	98.38	99.71	102.15	97.93	81.99	79.37	67.57	70.57	893.24

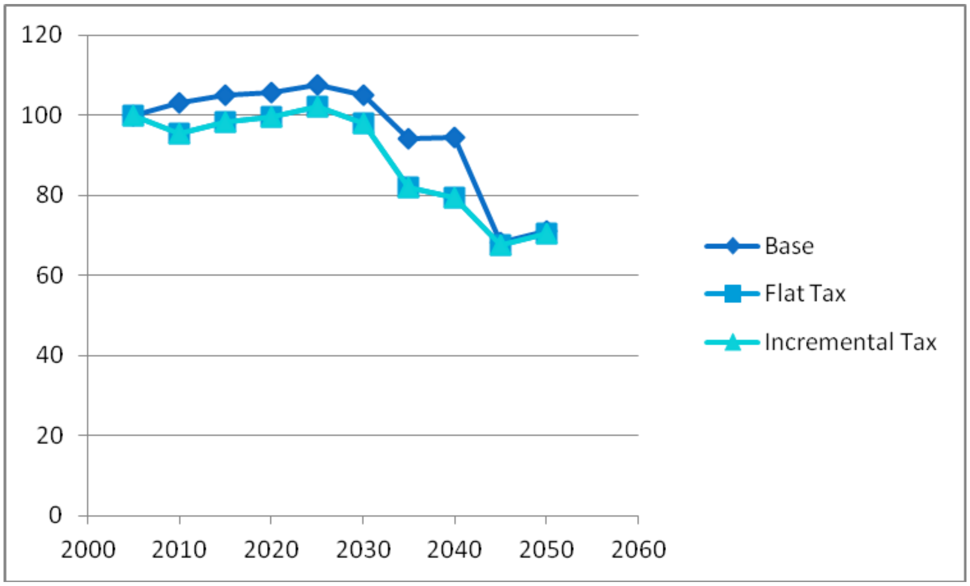

Figure 3: Indexed Total CO2 Emissions

CONCLUSIONS

The values of cost and CO_2 emissions are presented as indexes, as this allows for simpler and clearer comparisons. The baseline scenario represents a “business as usual” path. As noted by the difference between the flat tax and baseline values, a flat $10 tax yields a 3.1% lower cumulative cost and 6.4% cumulative drop in CO_2 emissions. In contrast, the incremental tax maintains a nearly identical cost and the same 6.4% cumulative drop in CO_2 emissions. As Long Island has many older electricity generating facilities, during the short term planning period there is the immediate drop off of CO_2 emissions, as older facilities are quickly phased out. Increasing the tax during the medium range and long term planning horizon does not initiate further CO_2 reduction, it only increases total system costs. The reduction of emissions was carried out by reducing distillate fuel oil dependence and increased usage of efficient natural gas combined cycle facilities. Another area of interest was the maintained dependence on waste to energy facilities. This is important and possibly somewhat unique to Long Island, as land filling has been banned on Island and waste must be incinerated or carted off Island at a large cost. This analysis clearly shows that a major issue for climate change action by way of a carbon tax is not necessarily how high the tax is, but when and where the tax is implemented. In an area like Long Island, with older facilities, short term regulations or policies will have a long standing effect. One of the limitations of this study is that we have information on only a limited range of future power plant designs. We would expect that the introduction of a carbon tax on power plant emissions will drive the technology for carbon reduction (or sequestration), which might potentially amplify the environmental and economic effects of such policies.

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