IMPACTS OF COSTS OF ADVANCED TECHNOLOGIES AND CARBON TAX RATES ON REVENUE

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Abstract

A primary reason for implementing a carbon or greenhouse gas tax is to reduce emissions but in recent years there has been increased interest in a carbon tax's revenue potential. This revenue could be used for federal deficit reduction, to help finance income tax reform, support new spending priorities such as infrastructure spending, offset the burden of the tax on households, or other purposes. With an environmental goal to reduce emissions to very low levels, programs that become dependent on the revenue may come up short when and if carbon revenue begins to decline. To date, the revenue potential of a carbon tax has not been studied in detail. This study focuses on how much carbon tax revenue can be collected and whether there is carbon “Laffer Curve” relationship, with a point where revenue begins to decline. We employ the MIT U.S. Regional Energy Policy (USREP) model, a dynamic computable general equilibrium model for the U.S. economy, for the numerical investigation of this question. To examine emissions and revenue responsiveness to the carbon tax, we consider scenarios with different carbon tax rate. We find tax revenue could peak at a high carbon tax level with more deployment of low-carbon technologies. To further explore the role of low-carbon technologies, we introduce a variation to the technology cost assumptions. Our preliminary results suggest that lower cost of abatement technology makes emissions more responsive to the tax rate. Hold the carbon tax rate constant, lowering the cost of low-carbon technology leads to less tax revenue collection. In terms of the peak timing, we find that the revenue peak comes earlier with lower cost of low-carbon technologies and tends to delay with higher cost of low-carbon technologies. The emission responsiveness to the carbon tax rate and technology cost assumption demonstrates the economic feedback that is the essence in Laffer Curve analyses.

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1. INTRODUCTION

The United States is living through a period of considerable climate policy uncertainty. While the Trump Administration moves forward with plans to withdraw the Clean Power Plan and dismantle much of the Obama Administration legacy on climate change, the general public appears increasingly concerned about climate change. According to one recent poll, voters feel the Trump Administration should not remove specific regulations to combat climate change.[1] Another poll focused specifically on Trump voters finds that nearly two-thirds of these voters support regulating or taxing greenhouse gas emissions.[2]

Meanwhile, the Republican agenda calls for major cuts in tax rates and the Trump Administration has discussed a major infrastructure spending package. A major obstacle to any of these initiatives is their potential impact on the federal budget deficit. Recently, a group associated with the Republican oriented American Action Forum proposed a "20/20" plan to combine a carbon tax starting at $20 a ton and growing at an annual 4 percent real rate with a cut in the corporate income tax rate to 20 percent. Coming from another direction, a group of senior Republican leaders including former Secretaries of State George Shultz and James Baker, former Secretary of the Treasury Henry Paulson as well as former heads of the Council of Economic Advisers, Martin Feldstein and N. Gregory Mankiw,

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1 Quinnipiac poll taken March 30 – April 3, 2017 available at https://poll.qu.edu/national/release-detail?ReleaseID=2449.

2 Leiserowitz, A., Maibach, E., Roser-Renouf, C., Cutler, M., & Rosenthal, S. (2017). *Trump Voters & Global Warming*. Yale University and George Mason University. New Haven, CT: Yale Program on Climate Change Communication, available at http://climatecommunication.yale.edu/publications/trump-voters-global-warming/ accessed on April 12, 2017.

have proposed a $40 per ton carbon tax rising over time with revenues rebated to U.S. families through a monthly carbon dividend.[3]

A primary reason for implementing a carbon or greenhouse gas tax is to reduce emissions. The policy initiatives above, however, speak to the increased interest in a carbon tax's revenue potential. In the United States context, this revenue could be used, among other uses, for federal deficit reduction, to help finance income tax reform, or support new spending priorities. Carbon revenue for new initiatives might net out some funding for temporary transitional assistance or to address concerns about impacts on low-income households. But even after some set-aside, there could be considerable revenue for other uses in the federal budget.

Given the environmental goal of ultimately reducing emissions to very low levels, programs that become dependent on the revenue may face funding challenges when and if carbon revenue begins to decline. To date, the revenue potential of a carbon tax has not been studied in detail. This study focuses on how much carbon tax revenue can be collected and at what point the tax revenue peaks and starts to decline. In other words, we explore the carbon "Laffer Curve" relationship that postulates a trade-off between the carbon tax rate and revenue. We calculate the revenue maximizing carbon tax rate both for the carbon tax alone and for the Federal tax system as a whole. That latter calculation takes into account changes in corporate and personal income tax collections due to reduced economic activity in response to implementation of carbon taxes.

To carry out this analysis, we employ the MIT U.S. Regional Energy Policy (USREP) model, a dynamic computable general equilibrium model for the U.S. economy, for the numerical investigation of this question. We consider scenarios with different carbon prices and emissions reductions goals to explore how that may affect whether and at what tax rate revenues peak. We find that whether and

[3] The American Action Forum 20/20 plan is described at https://www.americanactionforum.org/research/tax-reform-initiative-group-briefing-book/. The tax and dividend plan is described at https://www.clcouncil.org/.

when revenues peak will depend on the cost of low carbon technology alternatives. To examine emissions and revenue responsiveness to the carbon tax, we bring in a range of cost estimates of the abatement technologies. Our preliminary results suggest that higher rate of abatement technology deployment makes emissions more responsive to the tax rate and thus the revenue maximizing tax rate falls in level and appears earlier in time.

Our paper proceeds as follows. The next section describes the USREP model that we use for the analysis. We then discuss the various scenarios we consider. The following section discusses the results and draws some policy implications. We conclude with thoughts for further analysis.

2. THE MODEL

2.1 Data

The USREP model is built on an energy-economic dataset of the U.S. economy. For the purpose of energy and environmental policy study, we improve the input-output dataset at the state-level prepared by IMPLAN (IMPLAN, 2009) by replacing its energy accounts with physical energy quantities and energy prices from Energy Information Administration State Energy Data System (EIA-SEDS, 2009) for the same benchmark year 2006. The final dataset is rebalanced using constrained least-squares optimization techniques for a consistent representation of the economy. More data sources are used to improve the model parameterization. Figure 1 provides an overview of the data sources used for constructing the model.

We aggregate the dataset to 12 U.S. regions, 11 sectors, and 9 households grouped by annual income classes. The regional definition characterizes separate electricity interconnects, and captures some of the diversity among states in consumption and production of energy. The 509 commodities are aggregated to five energy sectors and six non-energy sectors. The energy sectors include coal (COL), natural gas (GAS), crude oil (CRU), refined oil (OIL) and electricity (ELE). The non-energy sectors include energy-intensive industries (EIS), agriculture (AGR), commercial transportation (TRN), personal transportation (HHTRN), services (SRV) and all other goods (OTH). Primary factors include labor, capital, and land, as well as fossil fuels and other natural resources. Households across income classes differ in terms of income sources and expenditure patterns.

Figure 1: USREP Data Sources

Data and Parameters	Source
Social Accounting Matrices	Minnesota IMPLAN Group (2008)
Pooled energy trade	Energy Information Administration - State Energy Data System (EIA-SEDS, 2009)
Physical energy flows and energy prices	Energy Information Administration - State Energy Data System (EIA-SEDS, 2009)
Fossil fuel reserves and biomass supply	U.S. Geological Survey (USGS, 2009) U.S. Department of Energy (DOE, 2009) Dyni (2006) Oakridge National Laboratories (2009)
High-resolution wind data	National Renewable Eenrgy Laboratory - Wind Integration Datasets (NREL, 2010)
Non-CO_2 GHG Inventories and endogenous costing	U.S. Environmental Protection Agency (EPA, 2009) Hyman et al. (2002)
Marginal personal income tax rates	NBER's TAXSIM model (Feenberg and Coutts, 1993)
Trade elasticities	The GTAP 7 Data Base (Narayana and Walmsley, 2008) and own calculation Own calculation
Energy demand and supply elasticities	MIT EPPA model (Paltsev et al., 2005)
Passenger vehicle transportation	U.S. Department of Transportation - Federal Highway Administration (FHWA, 2006) Karplus's calculation

Our dataset permits calculation of existing tax rates comprised of sector and region-specific ad-valorem output taxes, payroll taxes and capital income taxes. The dataset has been augmented by incorporating regional tax data from the NBER TAXSIM model (Feenberg and Coutts, 1993) to represent marginal personal income tax rates by region and income class.

Energy supply is regionalized by incorporating data for regional crude oil and natural gas reserves from U.S. Department of Energy (DOE, 2009), coal reserves estimated by the U.S. Geological Survey (USGS, 2009), and shale oil (Dyni, 2006). Our approach to characterizing wind resource and incorporating electricity generation from wind in the model is described in detail in Rausch and Karplus (2014). We derive regional supply curves for biomass from data from Oakridge National Laboratories (2009) that describes quantity and price pairs for biomass supply for each state.

2.2 Model Overview

Our modeling framework draws on a multi-commodity, multi-region, multi-household numerical general equilibrium model of the U.S. economy. The model assumes a recursive-dynamic approach implying that economic agents have myopic expectations and base their decisions on current period information.

In each industry gross output is produced using inputs of labor, capital, resource, energy and intermediate material goods. We employ constant-elasticity-of-substitution (CES) functions to characterize how production technologies respond to changes in relative prices of inputs. All industries are characterized by constant returns to scale (except for fossil fuels and agriculture, which are produced subject to decreasing returns to scale) and are traded in perfectly competitive markets.

Consumption, labor supply, and savings result from the decisions of representative households in each region maximizing utility subject to a budget constraint that requires that full consumption equals income in a given period. Lacking specific data on capital ownership, households are assumed to own a pool of U.S. capital. That is, they do not disproportionately own capital assets within the region in which they reside. Given input prices gross of taxes, firms maximize profits subject to technology constraints. Firms operate in perfectly competitive markets and maximize their profit by selling their products at a price equal to marginal costs. In each region, a single government entity approximates government activities at all levels - federal, state, and local. Government provides public provisions subject to income from tax revenue net of inter-institutional transfers. For a fair welfare comparison, government consumption is held at the baseline level across all policy scenarios.

Figure 2: USREP advanced technologies

	Technology	Description
Electricity	**Biomass generation**	Convert biomass into electricity
	Wind / Solar	Intermittent wind/solar resources
	Wind / gas backup	Intermittent wind generatio with natural gas backup
	Wind / biomass backup	Intermittent wind generatio with biomass backup
	Advanced gas	Natural gas combined cycle (NGCC)
	Advanced gas / CCS	Natural gas combined cycle with carbon capture and sequestration
	Advanced coal / CCS	Integrated coal gasification combined cycle (IGCC) with carbon capture and squestration
	Advanced nuclear	Next generation of nuclear power plants
Fuel	**Coal gasification**	Converts coal into natural gas
	Shale oil	Converts shale oil into crude oil
	Biomass liquids	Converts biomass into refined oil
Personal Transportation	**PHEV**	Plug-In Hybrid Electric Vehicles
	CNG	Compressed natural gas vehicles
	EV	Electric vehicles

Advanced energy supply options are specified as "backstop" technologies that enter endogenously when they become economically competitive with existing technologies. Competitiveness of advanced technologies depends on the endogenously determined prices for all inputs, as those prices depend on depletion of resources, energy and environmental policies, and other forces driving economic growth. We adopt a top-down approach of representing technologies following Paltsev et al. (2005, p. 31–42) where each technology can be described through a nested CES function. Figure 2 summarizes the advanced technology options. Eight technologies produce perfect substitutes for electricity. Three technologies produce perfect substitutes for conventional fossil fuels. Three technologies provide alternative personal vehicle transportation.

We adopt a putty-clay approach where a fraction of previously installed capital becomes nonmalleable and frozen into the prevailing techniques of production. Vintaged production in a given industry that uses non-malleable capital is subject to a fixed-coefficient transformation process in which the quantity shares of capital, labor, intermediate inputs and energy by fuel type are set to be identical to those that prevailed in the period when the capital was installed. Each of the sector-specific vintages is tracked through time as a separate capital stock. This formulation means that the model exhibits a short-run and long-run response to changes in relative prices.

Our framework incorporates a detailed representation of passenger vehicle transport that permits projections of vehicle-miles traveled (VMT), fleet stock turnover, and fuel price-induced investment in fuel efficiency. This permits studies of policies that target improvements in vehicle fuel efficiency, differentiate between newly purchased and pre-existing vehicle stocks in each period, and result in changes in overall vehicle-miles traveled as well as the fuel use and GHG emissions of new and pre-existing vehicles.

The key features of the model relevant to this study are described above. More detailed description and discussion of the model features are available in Rausch et al. (2010a, 2010b).

3. SCENARIOS

We updated the USREP baseline since the most recent published work (Rausch and Reilly, 2015). The update includes incorporating the Corporate Average Fuel Economy (CAFE) standards for personal vehicle transportation into the baseline. Also represented in the baseline scenario are regional renewable portfolio standards (RPS) to reflect the various RPS programs in different states. We also updated natural gas resources with recent estimates. The resource update takes effect through resource depletion accounting in the recursive dynamic model where an endogenously determined natural gas price is computed given the available resources and market demand in each period.

We calibrate the model baseline to the AEO 2017 GDP projection through an adjustment of labor productivity. In addition, we apply marginal tax rates to represent better deadweight loss associate with them. Part of the tax revenue raised by applying marginal rates on the entire tax base in each income class is rebated to that income class to reflect deductions and lower infra-marginal rates that exist in the tax code. We adjusted the rebated amount so that the effective revenue government raised through taxes was calibrated to AEO 2017 projections.

To examine the carbon "Laffer Curve" relationship between carbon tax rate and tax revenues, we designed a set of carbon policy scenarios that include (1) a low carbon tax starting at $20 per ton of CO_2 and rising at 4 percent real from 2020 to 2050; and (2) a high carbon tax starting at $100 per ton of CO_2 and rising at 4 percent real from 2020 to 2050.

When it comes to the sensitivity of tax revenue to the cost of low-carbon technology options we developed low, high and median technology costs. USREP follows the same approach the MIT EPPA model (Chen et al., 2014) adopts to parameterizing backstop technologies. The costs of backstop technologies are defined by a "markup" factor determined by the cost of the technology relative to the cost of the conventional generation against which it competes in the base year of the model (Morris et al., 2014). The cost of these backstop technologies are highly uncertain as illustrated in a recent International Energy Agency study (IEA, 2015). By adjusting the markup factor, we can simulate a case with different cost assumptions of backstop technologies. For our purposes of focusing on revenue which electricity option is lower cost doesn't matter. For simplicity we altered the cost markup for advanced nuclear. It is 1.327 at our Reference level, and we use 2.13 the HighCost case and 1.1 for the LowCost case. So, for example, the markup of 1.327 in the Reference scenario means that the levelized cost of electricity from advanced nuclear power is 32.7 percent higher than the levelized cost of electricity from coal-fired generation. To maintain revenue neutrality, a portion of the carbon tax revenue is reserved to replace any reduction in income tax collections brought about by the carbon tax and the rest of the revenue is distributed lump-sum to the households. We run the same tax scenarios for each of these markup factors levels. Table 1 provides a map with labels for each scenario.

Table 1: Scenarios

TECHNOLOGY COST DIMENSION	POLICY DIMENSION		
	Baseline	**Low Tax Scenarios**	**High Tax Scenarios**
	Reference	LTax_Ref	HTax_Ref
	HighCost	LTax_HCost	HTax_HCost
	LowCost	LTax_LCost	HTax_LCost

4. RESULTS

4.1 Carbon prices

Figure 3 shows that low tax scenarios start with a \$20/tCO_2 in 2020 growing at 4% per year up to \$65/tCO_2 in 2050. The high tax scenarios start with a \$100/tCO_2 in 2020 growing up to \$324/tCO_2 by 2050 in the HTax_Ref case.

Figure 3: Carbon prices (2006\$/tCO_2)

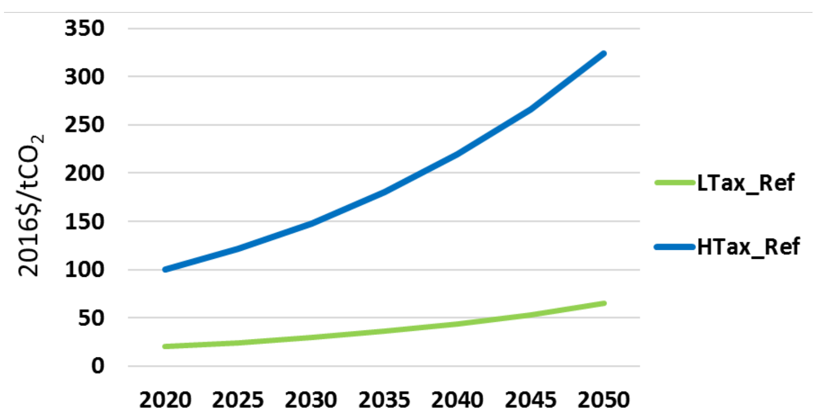
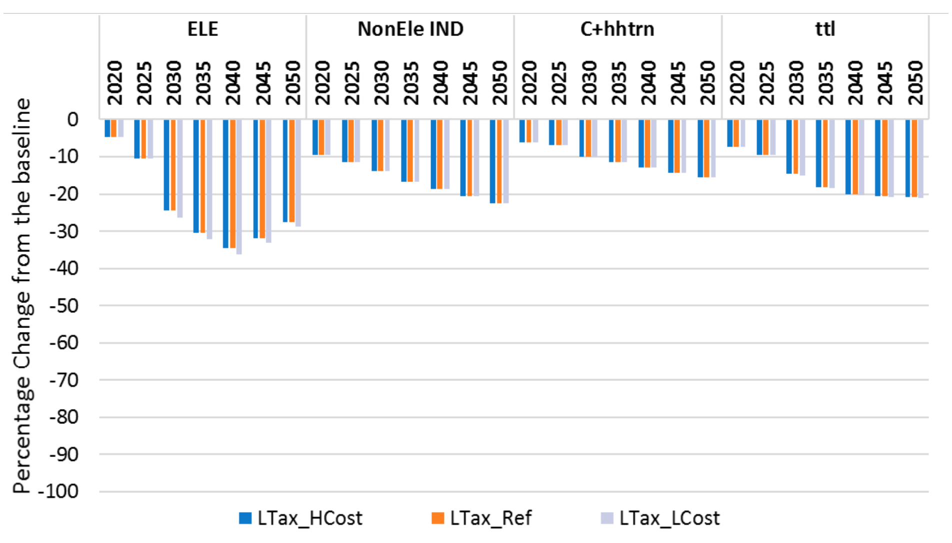


Figure 4 shows the percentage change of emissions reductions by different categories: the electric sector (ELE), the non-electric industries (Non-ELE IND), household consumption and personal transportation (C+HHTRN), and the economy-wide emissions (Total). To compare the impact of the same policy under different scenarios, we group the low tax scenarios in Figure 4 (a) and the high tax scenarios in Figure 4 (b). Consistent with the carbon prices, the low tax scenarios reduce much less emissions. Relative to the baseline levels, three low tax scenarios result in almost the same emissions reduction of 10% by 2025 and 20% by 2050.

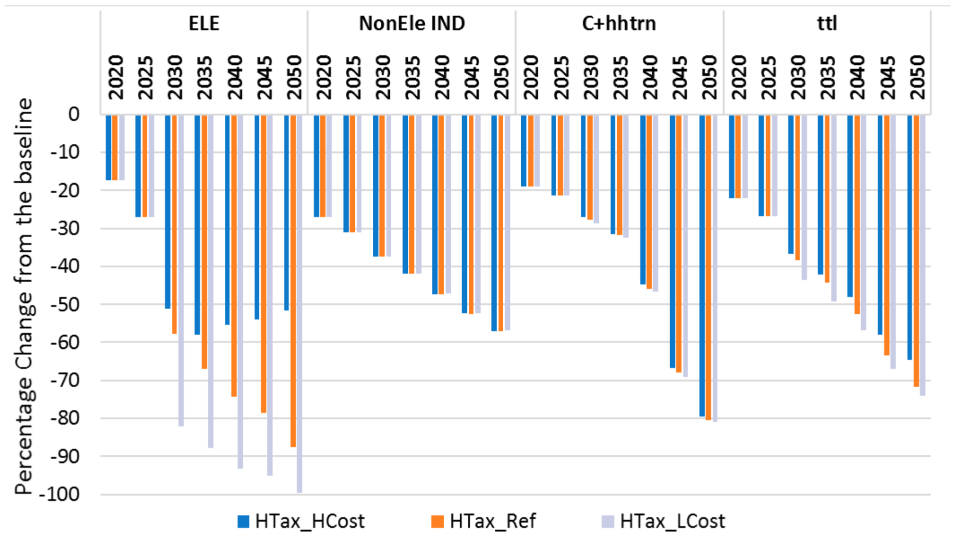
With a high carbon tax, emissions reductions are different with respect to the cost of backstop technologies. The HTax_Ref scenario with a median technology cost results in 72% reduction by 2050 relative to the baseline. The HTax_LCost scenario adopts more advanced nuclear and further cuts the emission to 74% by 2050. The advance nuclear is not viable in the HTax_HCost scenario, thus emissions reductions are limited in this case.

Across different cost scenarios, more reductions are resulted in the LowCost case starting in 2030 and the reductions are driven by advanced nuclear that comes online for electricity generation. Across sectors, the electric sector reduces more than the non-electric industrial sectors. Household consumption and personal transportation, due to the lack of low-cost low-carbon technologies, does not reduce as much, except for the last several periods where high carbon prices induce more fuel efficient vehicle for abatement.

Figure 4: Emissions reductions by sector



(a) Low tax scenarios

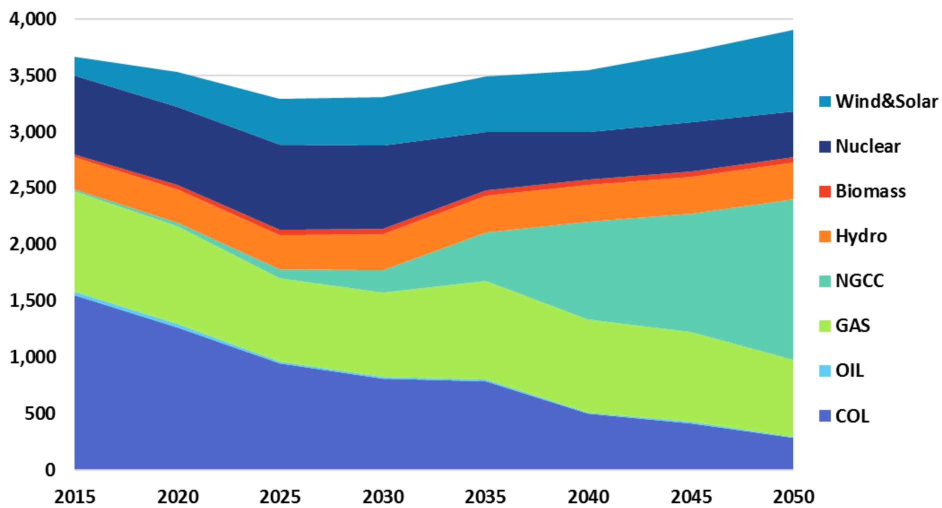


(b) High tax scenarios

4.2 Electricity generation and prices

Figure 5 shows the generation profile in the Reference scenario. Coal-fired generation declines to about one fifth of the 2015 level by 2050. Over the same period, nuclear generation reduces by a half. Wind and Solar is quadrupled and biomass electricity is doubled. The most increase comes from natural gas combined cycle (NGCC) which expands rapidly from supplying 2% of total generation in 2025 to more than a third by 2050. No advanced nuclear is deployed in the Reference case given its cost competitiveness. In the HighCost scenario, generation profile remains because higher cost of advanced nuclear does not change the economics of the online generation technologies. The LowCost scenario share the same generation profile implying that the cost of advanced nuclear is not low enough to come online. Thus, all three baseline scenarios share the same generation profile as in the Reference scenario.

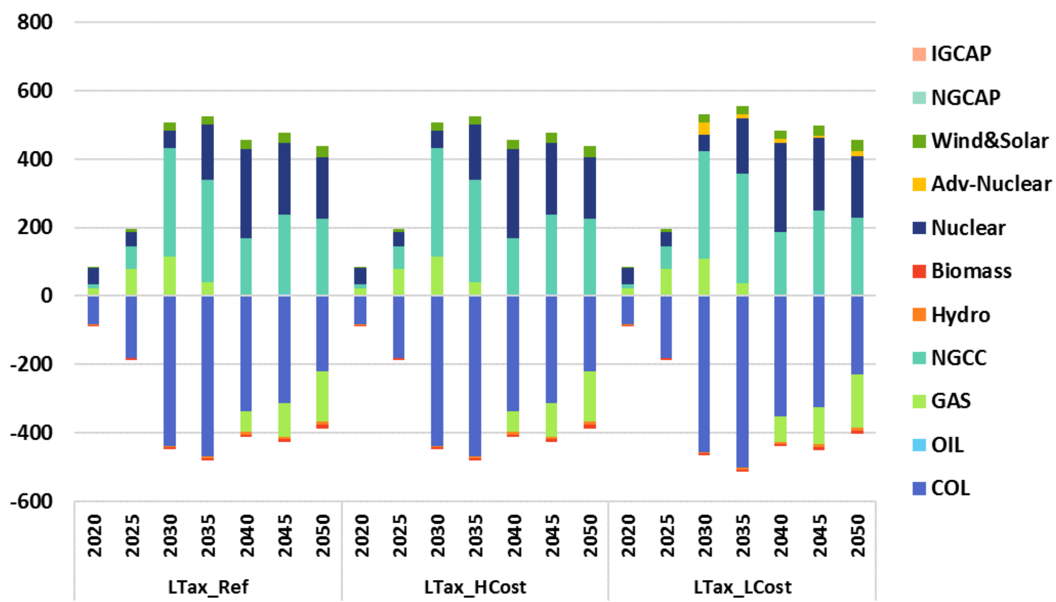
Figure 5: Baseline electricity generation (TWh)



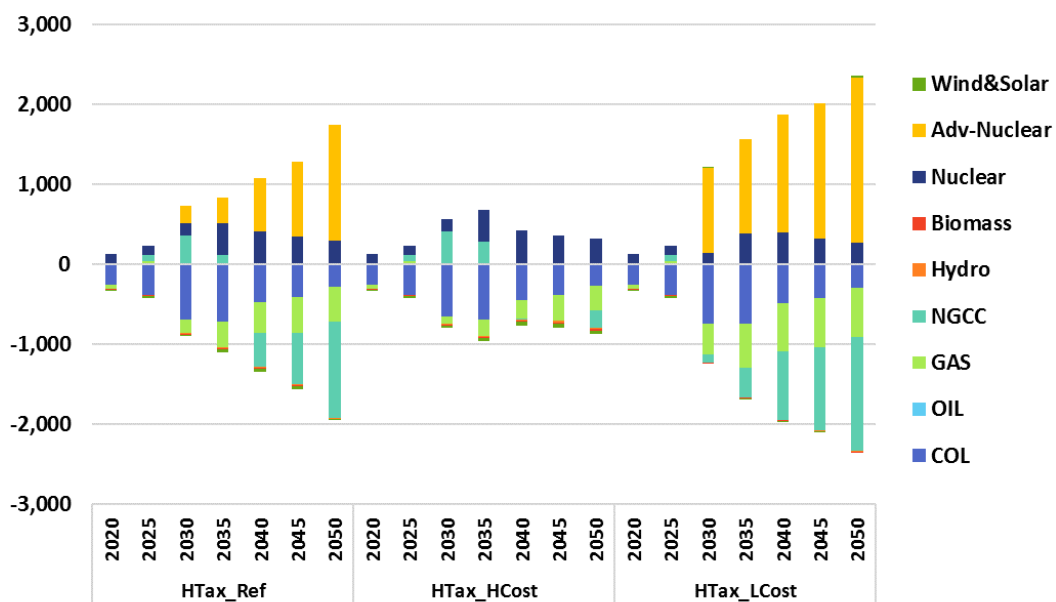
A carbon price changes the cost competitiveness among generation technologies, making fossil based generation relatively more expensive and the low-carbon or zero-carbon technologies less expensive, thus creating the potential to deploy more low-carbon and zero-carbon technologies to minimize the cost of electricity production. Figure 6(a) and Figure 6(b) show the changes in generation mix due to the low tax and high tax policy, respectively. With a low carbon tax, conventional fossil-fired generation is substituted with NGCC, nuclear and renewables. The LTax_HCost profile remains as in the LTax_Ref case, implying that the carbon price is insufficient to makes advanced nuclear cost competitive. As the cost of advanced nuclear decreases in the LTax_LCost scenario, there is marginal penetration of advanced nuclear starting in 2030.

In the high tax scenarios, advanced nuclear penetrates in 2030 in the HTax_Ref and HTax_LCost scenarios and expands quickly to substitute for conventional fossil-fired generation as well as NGCC. Note that advanced nuclear is not viable in the HTax_HCost scenario, hence NGCC does not phase out as rapidly as in the other two scenarios.

Figure 6: Scenario electricity generation (difference relative to the baseline in TWh)



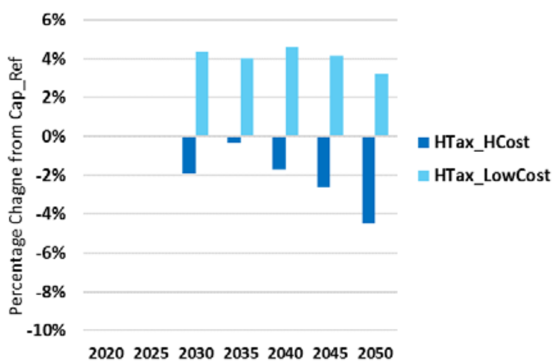
(a) Low tax scenarios



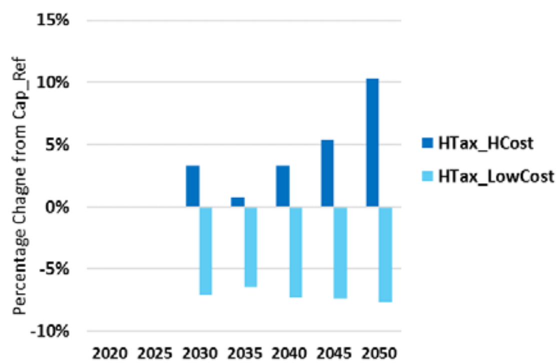
(b) High tax scenarios

Compared to the low tax scenarios, variation across the high tax scenarios is more pronounced. The HTax_HCost scenario drops advanced nuclear in most years since it is not economical to retain whereas the HTax_LCost scenario takes the cost advantage adding more advanced nuclear for electricity production. As expected, starting in 2030 when advanced nuclear penetrates, electricity supply increases in the HTax_LCost scenario and decreases in the HTax_HCost scenario. Figure 7(a) shows the change in electricity supply relative to HTax_Ref given a cost variation under the high carbon tax. Low technology cost results in greater supply of 4% for most year post 2030, whereas the high technology cost dampen the supply from 2% in 2030 to about 4% by 2050. Figure 7(b) shows consistent electricity prices response. Relative to the HTax_Ref scenario, cost of generation spans from a decline up to 7% in the HTax_LCost scenario to an increase of 10% in the HTax_HCost scenario by 2050.

Figure 7: Electricity supply and cost of generation



(a) Electricity supply



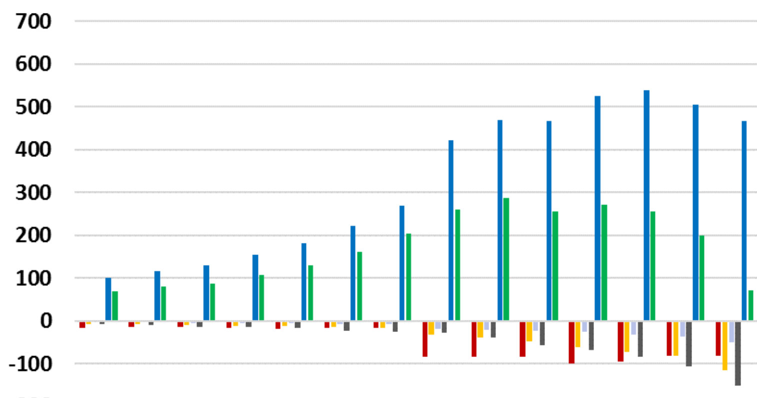
(b) Cost of generation

4.3 Tax revenue

With a carbon price, cost of production increases, leading to lower demand for sectoral output hence lower demand for factors of production. Tax revenue collected on labor through the payroll and personal income tax, on capital through the corporate and personal income tax, and other taxes will fall due to the slow-down of economic activities. The net tax revenue given all these changes, labeled as "Total" in Figure 8, is the amount actually received by government before giving a lump-sum rebate to the household. We first compare in Figure 8(a) how carbon tax affects the tax revenue under the same technology cost assumption, then we move on to compare in Figure 8(b) how the variation in technology cost assumption affects the tax revenue.

Under the median technology cost assumption, Figure 8(a) shows the changes in tax revenue by source for the low tax scenario and high tax scenario. The low tax scenario, LTax_Ref, raises carbon tax revenue from $100 billion in 2020 growing monotonically to $270 billion by 2050.[4] Compared to the low tax scenarios, carbon tax revenue stream in HTax_Ref does not increase monotonically. It starts with $423 billion in 2020, peaks at $539 billion in 2040 then declines to $467 in 2050. As the carbon tax is high enough, the carbon revenue suggests a Laffer Curve relation between the carbon tax and the carbon revenue collection. Similar to the carbon revenue, the net tax revenue exhibits a similar Laffer Curve pattern, peaking earlier at $272 billion in 2035.

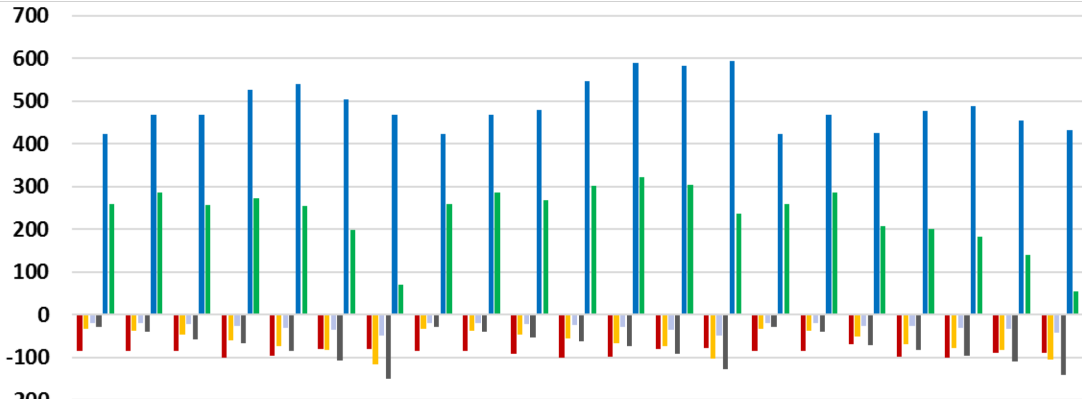
Figure 8: Tax revenue by source (Change relative to the baseline, Billion 2016$)



	LTax_Ref 2020	2025	2030	2035	2040	2045	2050	HTax_Ref 2020	2025	2030	2035	2040	2045	2050
Personal Income Tax	-16	-14	-15	-16	-18	-16	-17	-84	-84	-85	-100	-95	-81	-81
Payroll Tax	-6	-8	-9	-11	-13	-15	-17	-32	-39	-48	-60	-73	-82	-115
Corp. Income Tax	-4	-4	-5	-4	-5	-7	-7	-19	-21	-23	-26	-31	-36	-49
Other Tax	-7	-9	-14	-15	-17	-23	-26	-28	-39	-57	-68	-85	-107	-151
Carbon Tax	101	116	129	155	182	222	270	423	468	468	526	539	505	467
Total	68	81	87	108	131	161	203	259	286	256	272	255	199	71

(a) Low tax and high tax scenario with reference cost of backstop technology

[4] The tax scenarios in the study result in monotonically increasing revenues without running into a peak. We have run a high carbon tax scenario which results in a similar pattern in tax revenue just as in the cap scenarios.



	2020	2025	2030	2035	2040	2045	2050	2020	2025	2030	2035	2040	2045	2050	2020	2025	2030	2035	2040	2045	2050
	HTax_Ref							HTax_HCost							HTax_LCost						
Personal Income Tax	-84	-84	-85	-100	-95	-81	-81	-84	-84	-91	-101	-99	-81	-79	-84	-84	-69	-98	-100	-89	-90
Payroll Tax	-32	-39	-48	-60	-73	-82	-115	-32	-39	-46	-57	-66	-73	-103	-32	-39	-52	-68	-79	-82	-104
Corp. Income Tax	-19	-21	-23	-26	-31	-36	-49	-19	-21	-22	-24	-29	-34	-48	-19	-21	-25	-27	-31	-32	-42
Other Tax	-28	-39	-57	-68	-85	-107	-151	-28	-39	-52	-62	-74	-91	-128	-28	-39	-71	-83	-97	-110	-142
Carbon Tax	423	468	468	526	539	505	467	423	468	480	546	590	582	594	423	468	426	478	490	455	432
Total	259	286	256	272	255	199	71	259	286	269	303	321	303	237	259	286	209	202	183	141	55

(b) High tax scenario with varying cost of backstop technology

With a high carbon tax, Figure 8(b) compares tax revenue by source resulted from different technology cost assumptions. All three scenarios exhibit similar Laffer Curve shape in both carbon tax revenue and net tax revenue collections. Our comparison focuses on the post-2030 period when advanced nuclear creates difference across scenario. We find carbon tax revenue and net tax revenue are in positive relationship with technology cost assumption. Compared to the HTax_Ref scenario, carbon tax revenue in HTax_HCost peaks at higher level of about $590 billion and ends at higher level by 2050 whereas carbon tax revenue in HTax_LCost peaks at $490 in 2040 and declines faster than the HTax_Ref scenario to a lower revenue level of $432 billion by 2050.

Similar patterns are shown for the net tax revenue. Net tax revenue in HTax_HCost peaks at a higher level of $321 billion and ends at a higher level of $237 by 2050 whereas net tax revenue in HTax_LCost peaks at $209 in 2030 and declines faster than the HTax_Ref scenario to a lower revenue level of $55 billion by 2050.

In addition to the impact of technology cost assumption on revenue peak levels, we find that the revenue peak comes in different time with respect to different cost assumptions. In general, the revenue peak comes earlier under the low technology cost assumption and later when technology cost is higher. For the net tax revenue during the post-2030 period, HTax_Ref peaks in 2035, HTax_LCost peaks ealier in 2030 while HTax_HCost peaks later in 2040. Moreover, the net tax revenue peak comes ahead of the carbon tax revenue peak.

The results show tax revenue loss from the non-carbon sources due to carbon tax imposition. It also shows that the loss increases as carbon tax rate rises. That is, as more carbon tax revenue is collected, there is an offset brought about by the carbon tax from reduced economic activities. The offset, represented by a percentage of raised carbon tax revenue that is offset by the reduced tax revenue from other sources, ranges from 25% - 32% in the low tax scenarios, and 39% - 87% in the high tax scenarios. In contrast to our estimates, the Joint Committee on Taxation (JCT) uses a standard tax offset of 25 percent.[5]

Table 2: Non-carbon tax revenue loss (share by tax source)

	2020	2025	2030	2035	2040	2045	2050
Personal Income Tax	52%	46%	40%	39%	34%	26%	20%
Payroll Tax	20%	21%	22%	24%	26%	27%	29%
Corp. Income Tax	11%	11%	11%	10%	11%	12%	12%
Other Tax	17%	21%	27%	27%	30%	35%	38%

Breaking down the revenue losses by source, we find in Table 2 that personal income tax revenue contributes over half of the total revenue loss. Over time, the share of loss from personal income tax declines and that from the “other tax” more than doubles by 2050. The “other tax” include tax imposed on sectoral output, and the tax rate is higher on energy sectors, transportation and

[5] See JCX-7-16, *New Income And Payroll Tax Offsets To Changes In Excise Tax Revenues For 2016-2026*, available at https://www.jct.gov/publications.html?func=startdown&id=4869

services. The loss of the "other tax" reflects the reduced production from these sectors that are affected relatively heavily the carbon tax.

As far as the net tax revenue is concerned, we simulate three additional carbon tax scenarios with the median technology cost assumption, starting with a tax rate at $40, $60, and $80 per ton of CO_2 in 2020 rising at 4 percent real per year. We label these scenarios as "$40Tax _Ref", "$60Tax _Ref", "$80Tax _Ref", respectively. Figure 9 shows that from the $20 tax to $100 carbon tax, net tax revenue collection would be about $4600-$4800 in 2020 growing up to $6000-$6300 by 2050. These estimates should be considered together with the net tax collection reported for the Reference scenario.

Figure 9: Net tax revenue (Billion 2016$)

	2020	2025	2030	2035	2040	2045	2050
Reference	4,545	4,685	4,862	5,100	5,362	5,630	5,935
LTax_Ref	4,613	4,766	4,949	5,208	5,492	5,791	6,138
$40Tax_Ref	4,671	4,829	5,009	5,271	5,573	5,896	6,277
$60Tax_Ref	4,722	4,885	5,059	5,323	5,636	5,977	6,334
$80Tax_Ref	4,765	4,930	5,088	5,357	5,664	5,957	6,252
HTax_Ref	4,805	4,971	5,118	5,372	5,617	5,829	6,006

5. CONCLUSION

To examine emissions and revenue responsiveness to the carbon tax, we consider scenarios with different carbon tax rate. Holding the cost of low-carbon technologies constant, results show that the tax revenues do not peak at a low tax rate and there is little change in technology adoptions. At a high tax rate, both carbon tax revenue and the net tax revenue peak. To further explore the role of low-carbon technologies, we introduce a variation to the technology cost assumptions. Our preliminary results suggest that lower cost of abatement technology makes emissions more responsive to the tax rate. Hold the carbon tax rate constant, lowering the cost of low-carbon technology leads to less tax revenue collection. In terms of the peak timing, we find that the revenue peak comes earlier with lower cost of low-carbon technologies and tends to delay with higher cost of low-carbon technologies.

Furthermore, we observe that net tax revenue peaks ahead of carbon tax revenue. The emission responsiveness to the carbon tax rate and technology cost assumption demonstrates the economic feedback that is the essence in Laffer Curve analyses.

The results show that the reduced activities due to carbon tax imposition lead to loss of tax revenue from the non-carbon sources when the carbon tax increases. To assess how the carbon tax affects the net tax revenue collection, we calculate the offset brought about by the carbon tax from reduced economic activities. We find the offset in the low tax scenarios is comparable to the standard offset JCT uses and Congressional Budget Office (CBO) adopts. However, the high tax scenarios result in substantial offset, an increasing share of which comes from reduced sectoral output.

We also report the net tax revenue collections in the scenarios with median technology cost assumption.

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