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Designing by Degrees: Flexibility and Cost-Effectiveness in Climate Policy

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Abstract

Substantially reducing carbon dioxide (CO_2) emissions from electricity production will require a transformation of the resources used to produce power. This paper analyzes the economic consequences of a suite of different flexible and comprehensive policies to reduce CO_2 emissions from the power sector, including a carbon tax, a tradable emissions rate performance standard, and two versions of a clean energy standard (CES). A technology-based CES can bring about substantial reductions in CO_2 emissions but would neglect to harvest some economic reductions because it fails to affect decisions at three margins: emissions rate heterogeneity in the natural gas and coal generation fleets and electricity demand reductions. Natural gas emissions rate heterogeneity can be addressed by crediting clean generation based on emissions rates instead of technology. Coal emissions rate heterogeneity can be addressed by altering the policy to credit all generators instead of just a subset. Demand reductions can be harvested by removing the subsidy component of the policy and allowing retail electricity prices to rise. Harvesting emissions abatement on all three margins saves about 40 percent of the discounted cumulative economic welfare costs of a technology-based CES through 2035, although the distributional implications are different. All of the policies result in substantial increases in social welfare.

Key Words: clean energy standard, tradable performance standard, carbon tax, climate policy, electricity

JEL Classification Numbers: Q42, Q48, Q54, Q58

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Introduction

At the 2009 meeting of the United Nations Climate Change Conference in Copenhagen, Denmark, the United States issued a nonbinding pledge to bring its emissions of carbon dioxide (CO_2) in the range of 17 percent below 2005 levels by 2020 and 83 percent below 2005 levels by 2050. Given that the electricity sector is responsible for roughly 40 percent of US CO_2 emissions and that most of the cheapest emissions reductions opportunities are in the power sector, it has been and will continue to be a focal point in the effort to achieve the climate goals established at Copenhagen. Bringing about substantial reductions in CO_2 emissions from electricity production ultimately will require a transformation of the resources used to produce power. A key to mitigating the costs is to deploy flexible policy mechanisms. The extent of flexibility varies across different policy proposals that are germane to the debate.

A host of flexible policy options exist and have been considered in recent years in various jurisdictions. The most flexible approach, preferred by economists, is a carbon tax that imposes a fee on every ton of CO_2 emitted. Carbon taxes have been discussed recently not only as environmental policy, but also as a tool to facilitate tax reform or deficit reduction (Carbone et al. 2013). The dual fiscal and environmental benefits are an appeal, and, if the tax revenues are used in an efficient manner, the net economic benefits of a carbon tax exceed those of any other policy mechanism to reduce CO_2 from the power sector. Cap-and-trade policies limiting CO_2 emissions from the power sector that exist in the Regional Greenhouse Gas Initiative (RGGI) and California provide incentives for reducing CO_2 emissions that are similar to those of a carbon tax

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but not identical, as the CO_2 emissions allowances are allocated in ways that mute electricity price impacts. The US Environmental Protection Agency (EPA) has already established a proposed rule governing CO_2 emissions from new investments in fossil-fired electricity generators, and the agency is currently developing regulations for emissions from existing generators. These regulations are being promulgated under the Clean Air Act, and EPA may ultimately issue guidelines to states that allow for a tradable CO2 emissions rate performance standard (TPS), among other options. A TPS creates weaker incentives for reducing CO_2 emissions through reductions in electricity demand than a carbon tax, but it can still provide flexibility to the supply side of power markets and bring about substantial emissions reductions (Burtraw and Woerman 2013b).

Another approach to reducing carbon emissions is the provision of incentives for deployment of non- or low-CO_2-emitting generation technologies to displace existing carbon-intensive generation. In this vein, roughly 30 states have adopted renewable portfolio standards (RPS) that impose a minimum share on electricity supplied by renewables. A clean energy standard (CES) is a broader-based technology policy that expands on the RPS to include other nonemitting and low-emitting generation technologies, like nuclear and natural gas–fired generation. Such a policy was mentioned by President Obama in his 2011and 2012 State of the Union addresses and proposed in the Clean Energy Standard Act of 2012 (S 2146) by Senator Bingaman (D-NM).[2] A CES provides important incentives for fuel switching from coal to natural gas and for investment in nonemitting generators to achieve emissions reductions, but under many designs, it tends to affect fewer margins for emissions reductions than a TPS. The details of the CES design can enhance or restrict its relative efficiency.[3]

How these carbon policy mechanisms—different forms of CES, TPS, and a tax (or tradable cap) on carbon emissions compare is the subject of this paper. In particular, we describe and analyze the differences among these policies, emphasizing the elements of flexibility and the incentives that are created under each one. The analysis proceeds by implementing the Haiku electricity market simulation model to align these mechanisms to yield identical CO_2 emissions

[2] According to the Center for Climate and Energy Solutions, four states have similar alternative energy portfolio polici that include other sources of generation beyond renewables. (See www.c2es.org/us-sttates-regions/policy-maps/renewable-energy-standards, accessed 2/26/2014).

[3] The details of the policy can also affect its distributional consequence and these effects are explored in Mignone et al. (2012).

reductions trajectories through 2035. With emissions held constant in this way, the policies can be compared on economic welfare costs alone because environmental damages from CO_2 emissions will be equivalent across the policies.[4] Our findings indicate that the carbon tax has the highest net social welfare followed by the TPS.

Analytical Discussion

Economic theory and empirical evidence in other contexts suggest that imposing a price on carbon emissions will achieve emissions reductions as cost-effectively as possible.5 A tradable emissions rate performance standard is a less cost-effective means of emissions mitigation than an emissions tax because the policy includes both a tax on emissions and a simultaneous subsidy to electricity generation that reduces incentives for energy conservation as a means to reduce emissions (Aldy 2012; Fischer 2001; Fischer and Fox 2007; Burtraw et al. 2005). A CES is an even blunter instrument that discourages generation from high-emitting technologies including coal and encourages the use of cleaner technologies to an extent determined by the crediting rate applied to generation from each type of technology and the level of the target.6 Within a CES framework, allowing for flexibility in crediting for emitting technologies based on their CO2 emissions rate relative to a benchmark will lead to a more cost-effective outcome than a strictly technology-based crediting scheme.7

In this section, we present an analytical evaluation of the incentive features of each policy, beginning with a description of the salient features of each in Table 1. The left-hand

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[4] Other environmental differences among the policies in terms of emissions of conventional pollutants may cause them to differ in total environmental costs. To the extent environmental benefits are addressed in this paper, the focus is exclusively on those associated with reduced emissions of CO_2.

[5] Because carbon taxes interact with preexisting distortionary taxes in complicated ways, the efficiency of a carbon tax will depend importantly on how the revenue is used (Bovenberg and Goulder 1997). Research has suggested that carbon taxes will be most efficient when the revenues are used to offset preexisting distortionary taxes; when this is not the case, and even when it is, the second-best optimal tax rate may differ from the social cost of carbon (Bovenberg and Goulder 2002).

[6] An RPS is an example of a more limited clean technology standard focused on renewables. A growing literature analyzes how differentiation of subsidies to renewables and RPS policies to account for differences in avoided emissions over time and across space can improve the environmental outcomes and lower the costs of these policies (Cullen 2013, Kaffine et al. 2013, Novan 2011, Siler-Evans et al. 2013).

[7] In theory, a CES policy could be designed in a way that would yield an outcome identical to that of a tradable emissions rate performance standard by crediting based on emissions rate and setting the emissions rate benchmark sufficiently high that every generator receives credits. A practical problem with this type of policy is that the high subsidy rates required to achieve the emissions rate target can result in negative energy prices.

column introduces abbreviated forms for the names of the policies that we use throughout the paper.

Several options are available for abating CO_2 emissions from the electricity sector. Emissions reductions can come from (a) switching within an emitting fuel and technology category (coal, natural gas combined cycle [NGCC], or other fossil) away from more emissions-intensive plants to cleaner ones, (b) making investments in efficiency improvements at existing coal-fired power plants (Linn et al. 2013), (c) switching from coal and other fossil to NGCC, (d) greater reliance on renewables and nuclear generation, and (e) demand reductions. The range and extent to which a policy encourages emissions reductions on the different abatement margins determine its cost-effectiveness. To describe the way that the policies in Table 1 affect the margins, we begin by decomposing the policies into component parts.

Table 1. Policy Specifications

Policy Name	Policy Description
CES Tech	**Tech**nology-based **C**lean **E**nergy **S**tandard sets a minimum share (%) of retail electricity sales (MWh) that must be supplied by clean generation sources. Clean energy credits are allocated to clean generation based on technology type. The credits are purchased in a market by local distribution companies from generators to meet the minimum share of sales requirement, and they acquire a market clearing price ($/MWh). Renewables, new nuclear, natural gas combined cycle and coal with carbon capture and storage (CCS) are eligible for credit allocation (credits/MWh); other technologies are not. Technologies that do not emit CO_2 receive a full credit for each MWh of generation; other credited technologies receive a partial credit. All generators in the same technology class have the same credit allocation rate. Implicit is that electricity generation is taxed ($/MWh), based on the credit burden of the local distribution companies, and subsidized by the credit allocation rate ($/MWh).
CES ER	Carbon **E**missions **R**ate–based **C**lean **E**nergy **S**tandard is identical to CES Tech except that the crediting rates (credits/MWh) do not depend on technologies, but instead depend on CO_2 emissions rates (tons/MWh). Crediting rates vary linearly with emissions rates, from a full credit for zero emissions rate to no credit at a reference emissions rate. Generators with an emissions rate above the reference rate receive no credits.
TPS	**T**radable emissions rate **P**erformance **S**tandard sets a fleet average CO_2 emissions rate standard (tons/MWh) across all generators and allows trading of credits to achieve the standard. A generator earns (owes) a credit on each MWh of generation for each ton/MWh that its emissions rate is below (above) the standard. Implicit is a tax on emissions ($/ton) and a subsidy to generation ($/MWh).
C Tax	**C**arbon **Tax** imposes a fee ($/ton) on each ton of CO_2 emissions (tons). There is no subsidy.

Each of the policies described in Table 1 can be decomposed into tax and subsidy components; formally expressing the decomposition reveals the nature of the incentives and flexibility inherent in each to reach the five abatement margins. The components are described mathematically in Table 2, which also characterizes the incentives for redispatch and investment/retirement within and between technology classes as a result of these two policy features. P_{Tech} is the clean energy credit price ($/MWh) in the CES Tech policy; P_{ER} is the corollary for the CES ER policy. T_{Tech} and T_{ER} are the targets for the clean share (%) of retail sales for the policies. $CR_{\text{Tech},t}$ is the crediting rate for generation (credits/MWh) by technology class t under the CES Tech policy; $CR_{\text{ER},i}$ is the corollary for the CES ER policy, but it can vary across all generating units i, even those within a technology class t. P_{CO2} is the price of a CO_2 allowance ($/ton) under the TPS policy, ER_i is the CO_2 emissions rate (tons/MWh) for unit i, ER_{Avg} is the fleet-wide average CO_2 emissions rate, and t_{CO2} is the CO_2 emissions tax rate ($/ton). In the subsequent simulation modeling analysis, we analyze the policy implications and welfare consequences of a particular level of emissions reductions under each policy.

The first two rows of Table 2 show that both CES policies impose a tax on electricity sales that is uniform across different types of generating units and depends on the product of the clean energy credit price and the CES target share of retail sales. In contrast, the subsidy component under both CES policies differs across generating units, but the CES Tech policy does not differentiate the subsidy for different units within a technology class, thereby failing to harvest cost-effective emissions reductions along that margin of heterogeneity. Under the CES ER policy, the crediting rate for each generating unit is set according to how it performs relative to a reference emissions rate, ER_{Ref}, by the formula, $CR_{\text{ER,i}} = \max\{0, 1 - ER_i/ER_{\text{Ref}}\}$. For a value of ER_{Ref} that is in between the emissions rate of the dirtiest NGCC generator and the cleanest coal boiler, all coal boilers will receive an identical crediting rate of zero. All NGCCs will receive credit and the rate will be differentiated within that technology class. These heterogeneous crediting rates for NGCCs are what provide an incentive for fuel switching among NGCC units (the first margin for emissions reduction) and thus make the CES ER policy more efficient at achieving emissions reductions than the CES Tech policy, under which all NGCCs have an identical crediting rate.[8] Both policies will reach the last three margins (coal/gas

[8] Note that the choice of ER_{Ref} will affect the average crediting rate across natural gas-fired units under CES ER and it may vary from 0.5, which is the rate under CES Tech. Such a difference between the two CES scenarios will lead to differences in the relative incentives to use natural gas versus other technologies. This is ignored in Table 2, but is addressed later in the simulation results.

switching, fossil/nonemitting switching, and demand reductions), though the impact on demand is smaller than will be found under C Tax. Neither policy reaches the second margin on efficiency investments at coal boilers.

Table 2. Subsidy and Tax Components of Policies

Policy	Tax			Subsidy		
	Rate	$/MWh Within Technology Classes	$/MWh Between Technology Classes	Rate	$/MWh Within Technology Classes	$/MWh Between Technology Classes
CES Tech	$P_{\text{Tech}} * T_{\text{Tech}}$	U	U	$P_{\text{Tech}} * CR_{\text{Tech},t}$	U	D
CES ER	$P_{\text{ER}} * T_{\text{ER}}$	U	U	$P_{\text{ER}} * CR_{\text{ER},i}$	D*	D
TPS	$P_{\text{CO2}} * ER_i$	D	D	$P_{\text{CO2}} * ER_{\text{Avg}}$	U	U
C Tax	$t_{\text{CO2}} * ER_i$	D	D	0	N/A	N/A

U indicates that tax/subsidy is uniform across identified group.
D indicates that tax/subsidy is differentiated across identified group.
D* indicates that differentiation occurs within the NGCC fleet, but not within the coal fleet

The CES ER policy excludes any generators with an emissions rate above the reference rate from receiving a subsidy. In this paper, as in S 2146, the recent legislative proposal introduced by Senator Bingaman) in 2012, the reference rate is set to exclude all coal boilers and include all NGCCs. Thus this CES policy does not provide any incentive for emissions reductions from within the existing fleet of coal boilers by either redispatch or investment to improve boiler efficiency (Linn et al. 2013).[9] The TPS policy addresses this inefficient feature of CES ER by requiring every generator, including coal boilers, to hold and surrender sufficient allowances to cover its actual CO_2 emissions rate over the course of a year. A TPS is identical to a cap-and-trade policy that allocates emissions allowances to all generators on the basis of current period electricity production. Generators with an emissions rate below the TPS target will

[9] Another way to provide incentives for greater efficiency in coal-fired generation is to raise the CES ER reference CO_2 emissions rate from 0.82 metric tons per MWh to a rate sufficiently high that every generating unit qualifies for at least some fraction of a clean energy credit. A CES with a carbon intensity reference rate high enough that all generators receive credits can be identical to a tradable carbon emission rate performance standard and to a cap on carbon emissions with an output-based allowance allocation scheme under certain assumptions.

get a net subsidy from the policy because they earn credits (through the output-based allocation scheme) at a higher rate per MWh generated than their actual emissions rate. Generators that emit at a higher rate than the TPS target must surrender more emissions allowances than they receive, so they must purchase them from other low-emitting generators.

This equivalence to a cap-and-trade policy is illustrated by the tax and subsidy rates reported in the TPS row of Table 2. Under a TPS, emissions are taxed at the price of CO_2 emissions allowances, so generation is taxed at the CO_2 price times the emissions rate at each generator. Electricity production is subsidized at a rate equal to the price of an allowance times the average emissions rate across all generators, including those that emit no CO_2. This policy creates a strong incentive to shift away from high-emitting sources of coal generation to more efficient coal-fired boilers, as well as an incentive for coal-fired generators to make investments to improve their heat rates and thereby reduce emissions of CO_2. By expanding the set of emissions mitigation strategies available to the power sector, a TPS policy is more flexible than either CES policy. It also increases the incentive to switch between the more efficient coal generators and NGCC because TPS differentially impacts the heterogeneous coal fleet to the benefit of the efficient generators while CES does not. Conversely, the TPS will provide a lower incentive than either CES policy to switch between less efficient coal generators and NGCC. As a consequence, either TPS or CES ER could be more cost-effective, depending on which generators are on the margin and the incentive for switching from the marginal coal generator to NGCC. This TPS policy reaches all five abatement margins, but like the CES policies, it does not reach as far on the demand margin as the C Tax will be shown to do.

The last policy described in Table 2 is C Tax. This policy encourages the broadest range of approaches to reducing CO_2 emissions by pricing emissions fully at all margins, including electricity consumption. Under the TPS and both CES policies, generation prices are held low through the use of a subsidy either to a subset of generation (in the case of the CES policies) or to all generation (in the case of the TPS policy). Under the C Tax scenario, the opportunity cost of incremental CO_2 emissions is reflected not only in operating and investment decisions made by generators, discouraging use of and investment in higher-emitting technologies in favor of lower-emitting or nonemitting options, but also in the electricity price, which discourages overall consumption of electricity as yet another means of reducing CO_2 emissions. If some amount of demand reduction is more cost-effective than other approaches to achieving the CO_2 emissions reduction target, then C Tax is the only policy of the four considered here that will provide an incentive for the efficient level of electricity conservation and for the overall efficient mix of emissions mitigation strategies.[10] Thus by having greater flexibility and operating on all abatement margins—fuel switching, dispatch changes, investments in heat rate reductions, investment in non-emitting technologies, and reductions in power consumption—C Tax is the most efficient approach to emissions mitigation (Paul et al. 2013a).

Model and Scenarios

Haiku

The Haiku electricity market model is a partial equilibrium model that solves for investment and operation of the electricity system in 22 linked regions of the contiguous United States, starting in 2013 and solving out to the year 2035 (Paul et al. 2009). Each simulation year is represented by three seasons (spring and fall are combined) and four times of day. For each time block, demand is modeled for three customer classes (residential, industrial, and commercial) in a partial adjustment framework that captures the dynamics of the long-run demand responses to short-run price changes. Supply is represented using 58 model plants in each region, including various types of renewables, nuclear-, natural gas–, and coal-fired power plants, and assumed levels of power imports from Mexico and Canada. Thirty-nine of the model plants aggregate existing capacity according to technology and fuel source from the complete set of commercial electricity generation plants in the country. The remaining 19 model plants represent new capacity investments, again differentiated by technology and fuel source. Each coal model plant is the aggregation of a range of capacities at various heat rates, representing the range of average heat rates at the underlying constituent plants.

Operation of the electricity system (generator dispatch) in the model is based on the minimization of short-run variable costs of generation, and a reserve margin is enforced based on margins obtained by the Energy Information Administration in the *Annual Energy Outlook*

[10] Because electricity markets are regulated, other factors may impede the C Tax policy from attaining the first-best outcome. In particular, if the price of electricity under average cost pricing is above the marginal cost of production, then adding a carbon tax could yield a price that is inefficiently high and electricity consumption that is inefficiently low. If, on the other hand, the price of electricity under average cost pricing is below the marginal cost of production, then adding a carbon price (as in C Tax) could yield a price that is inefficiently low and electricity consumption that is inefficiently high.

(AEO) for 2011 (EIA 2011). We do not model separate markets for spinning reserves and capacity reserves. Instead, the fraction of reserve services provided by steam generators is constrained to be no greater than 50 percent of the total reserve requirement in each time block. Fuel prices are benchmarked to the AEO 2011 forecasts for both level and supply elasticity.[11] Coal is differentiated along several dimensions, including fuel quality and content and location of supply, and both coal and natural gas prices are differentiated by point of delivery. The price of biomass fuel also varies by region depending on the mix of biomass types available and delivery costs. All fuels are modeled with price-responsive supply curves, except for nuclear fuel and oil, which are assumed constant.

Investment in new generation capacity and the retirement of existing facilities are determined endogenously for an intertemporally consistent (forward-looking with perfect foresight) equilibrium, based on the capacity-related costs of providing service in the present and into the future (going-forward costs) and the discounted value of going-forward revenue streams.[12] Existing coal-fired facilities also have the opportunity to make endogenous investments to improve their energy efficiency (Burtraw et al. 2012, Burtraw and Woerman 2013a). Discounting for new capacity investments is based on an assumed real cost of capital of 7.5 percent. Investment and operation include pollution control decisions to comply with regulatory constraints for SO_2, NO_x, mercury, hydrochloric acid (HCl), and particulate matter (PM), including equilibria in emissions allowance markets where relevant. All currently available generation technologies as identified in AEO 2011 are represented in the model, as are integrated gasification combined cycle coal plants with CCS and natural gas combined cycle (NGCC) plants with CCS. Ultrasupercritical pulverized coal plants and CCS retrofits at existing facilities are not available in the model.[13]

Price formation is determined by cost-of-service regulation or by competition in different regions corresponding to current regulatory practice. The retail price of electricity does not vary by time of day in any region, though all customers face prices that vary from season to season.

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[11] Note that natural gas prices in AEO 2011 are about 10–12 percent higher than in AEO 2013.

[12] Investment (in both generation capacity and pollution controls) and retirement are determined according to cost - minimization. This fails to account for the potential Averch-Johnson effect (see Averch and Johnson, 1962), which tends to lead to over investment in capital relative to fuel, and to raise costs.

[13] Although it is possible that CCS retrofits could be commercially viable before the end of our simulation horizon, we do not anticipate that it would play an important role throughout most of the horizon.

Scenarios

Five scenarios are simulated to illustrate the decomposition of the differences in incentives between C Tax and CES Tech. All of them except the baseline achieve equivalent CO2 emissions in each year from 2015 through 2035. This equivalence is achieved by first finding the emissions levels under a CES Tech policy and then adjusting certain specifications of the other policies, which are described in the remainder of this section, such that annual emissions from the electricity sector are identical to those under CES Tech.

Baseline (BL)

All of the features of the baseline scenario are held constant in all of the other policies, except as specifically described for each policy. The baseline scenario is calibrated to AEO 2011 and includes regulations under Title IV of the Clean Air Act, the Clean Air Interstate Rule (CAIR), and EPA's recently finalized Mercury and Air Toxics Standards (MATS). Title IV governs nationwide SO_2 emissions, setting the national-level constraint of 8.95 million emissions allowances annually. CAIR alters this constraint for plants in the eastern United States, which constitute the largest share of national SO_2 emissions. It changes the value of an emissions allowance for emissions in that region with vintage 2010 or later, requiring two allowances per ton in 2010 and increasing over time. Facilities outside of the CAIR region continue to operate under the Title IV constraint. CAIR also imposes annual and summertime emissions caps on nitrogen oxides in a similar, but not identical, group of states. MATS restricts emissions of heavy metals and acid gases from new and existing coal- and oil-fired power plants. It sets plant-specific emissions standards for mercury, regulates the emissions of filterable particulate matter as a surrogate for nonmercury heavy metals, and limits the emissions of hydrogen chloride as a surrogate for acid gases. MATS is expected to lead the cap on SO_2 emissions under CAIR to go slack, driving the Title IV allowance prices to zero (Burtraw et al. 2013). The baseline also includes state-level mercury regulations where they apply, the RGGI, all state-level renewable portfolio standards and renewable production tax credits, and federal renewable production and investment tax credits.

CES Tech

The technology-based CES scenario imposes a minimum percentage of electricity sales from clean energy of 45 percent in 2015, rising by 1 percentage point per year to 50 percent in 2020, then rising by 2 percentage points per year to 80 percent in 2035. The CES obliges all retail utilities to hold a fraction of clean energy credits equal to the requirement for each MWh of retail electricity sales. Clean energy credits are awarded for each megawatt hour of electricity generated by an eligible source at the designated crediting rate. Eligible clean sources include all renewable sources such as existing hydro, new and existing nuclear generators, NGCC units, and coal with CCS. All nonemitting technologies, including renewables, hydro, and nuclear, receive 1 credit per MWh of generation; NGCC units receive 0.50 credit per MWh (unless they have also CCS, in which case they receive 0.95 credit per MWh); and integrated gasification combined cycle (IGCC) units with CCS receive 0.90 credit per MWh. Coal-fired boilers get zero credits per MWh. Under this scenario, banking of CES credits is allowed, and thus the realized path of the clean energy percentage may deviate from the target path.

CES ER

The carbon emission rate–based CES scenario is a more flexible version of a CES than CES Tech. This scenario employs a crediting approach modeled after the CES policy proposed by Senator Bingaman.[14] The approach awards the maximum of 0 or 1 minus the ratio of a generator's CO_2 emissions rate to 0.82 metric tons of CO_2 for each MWh of electricity generated. The 0.82 emissions rate threshold falls below the CO_2 emissions rate for any existing coal-fired boiler, so all coal boilers receive zero credits.[15] The level of the CES target in each year is determined by the requirement that this scenario achieve the same level of annual CO_2 emissions as the CES Tech scenario. The resulting target level for the standard starts at 53 percent in 2015, rises to about 59 percent in 2027, and then increases more rapidly to nearly 80 percent by 2035. To ensure that emissions line up in each year, no banking of clean energy credits is allowed.

[14] The policy modeled here differs from the Bingaman proposal in the Clean Energy Standard Act of 2012 in some important ways. First, the Bingaman CES included an alternative compliance payment that capped the price of clean energy credits, and analysis suggests that the cap would be binding (Paul et al. 2013b). The Bingaman proposal also excluded small utilities from having to comply with the policy, did not credit generation from nuclear andor hydro units that entered service prior to 1992, and excluded generation from these units from coverage under the Clean Energy Standard.

[15] In addition to allowing for differences in crediting among different natural gas units, the CES ER scenario also results in a slight difference in the average crediting rate for natural gas units than under the CES Tech scenario. This difference occurs because the emission rate standard was selected to represent the standard in the Bingaman bill rather than a standard that would result in the same average crediting for gas units as under CES Tech. Also, the CES ER scenario allows crediting of gas combustion turbines and natural gas steam boilers, which do not receive credits under CES Tech. These units are responsible for only a small portion of natural gas generation. The average crediting rate results for natural gas units are discussed around Table 3.

TPS

The tradable CO_2 emissions rate performance standard (TPS) imposes an annual average CO_2 emissions rate standard, which constitutes the crediting rate for all generators, and allows for credit trading among generators. The emissions rate target is set in such a way as to yield annual CO_2 emissions outcomes identical to those under the CES Tech scenario in all years. The target starts at 0.49 short tons per MWh in 2015, decreases to 0.47 tons per MWh in 2020, and then falls to 0.23 tons per MWh in 2035.[16] For modeling purposes, this policy is identical to a cap-and-trade policy where emissions allowances (denominated in tons set equal to the annual CO_2 emissions results from the CES Tech scenario) are allocated to all generators based on the contemporaneous quantity of electricity produced.[17] To ensure that emissions line up in all years, no banking of emissions credits is allowed.

C Tax

The C Tax scenario imposes a tax on emissions of CO_2 from the power sector. The level of the tax is determined by the tax rate necessary to achieve CO_2 emissions in each year identical to those under the CES Tech scenario described above. The level of the carbon tax necessary to achieve this result goes up over time, starting at $18 per short ton of CO_2 in 2015, growing to $20 per ton by 2020, and then increasing more rapidly to reach $66 per ton by 2035.[18]

Simulation Results

Emissions

Total CO_2 emissions from the electricity sector under each of the policies are presented in Figure 1. By design, each of the policy scenarios yields the same level of emissions, which is defined as the level of emissions that results in each year under the CES Tech scenario. Emissions are about 1.9 billion tons in 2020, a 0.5 billion ton (21 percent) reduction from

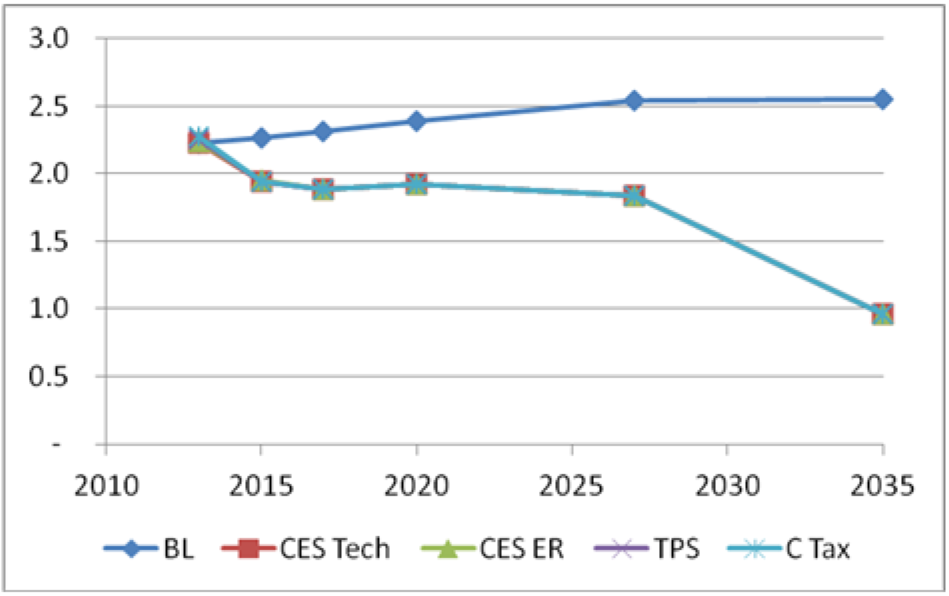
[16] These targets are equivalent to 0.44, 0.43, and 0.21 metric tons per MWh, respectively.

[17] A tradable performance standard could be applied to a subset of generators instead of the entire fleet. In particular, some analysts expect forthcoming regulations of CO_2 emissions from existing sources to take the form of tradable performance standards for emitting generators only (Burtraw and Woerman 2013b).

[18] These tax rates are equivalent to $19 per metric ton of CO_2 in 2015, $22 per metric ton of CO_2 in 2020 and $73 per metric ton of CO_2 in 2035.

baseline levels, and by 2035, they fall to just below 1 billion tons, which is 60 percent below baseline.[19]

Figure 1. CO_2 Emissions (billion short tons)



Taxes and Subsidies

As discussed above, each of the four policies can be represented as a combination of a tax on carbon emissions and a subsidy to power generation. The sizes of the subsidies for the two CES policies vary by technology and are determined based on the crediting rates and the credit prices, the latter of which depends on the clean energy targets specified by the policy for each year. The tax rates for the CES cases are equal to the clean energy credit price times the clean energy target and do not vary by technology. For the TPS and C Tax scenarios, the tax rate varies across technologies depending on emissions rates, and the subsidy rate is the same for all technologies. In the case of TPS, the subsidy is equal to the emissions rate standard times the market price of CO_2, and for C Tax, the subsidy is zero.

The tax and subsidy rates (in \$/MWh) by technology class under each of the policies are reported in Table 3 for 2020 and 2035. The net tax rate is the difference between the tax and the

[19] Tons here and throughout thisthe Simulation Results section are short tons unless specified otherwise. In this case, the emissions reductions are equivalent to 1.7 billion metric tons in 2020 from a baseline emissions level of 2.1 billion metric tons and 0.9 billion metric tons in 2035 from a baseline emissions level of 2.3 billion metric tons. .

subsidy; it is typically negative or zero for nonemitting technologies and typically positive for emitting technologies with the exception of generation from new NGCC units under some policies in 2020. The differences in net tax rates for a given technology across scenarios and the differences in relative net tax rates across technologies among different scenarios reveal how these different policies shape incentives to alter dispatch and investment decisions to reduce CO_2 emissions.

Moving from a CES Tech to a CES ER policy leads to differentiation in the net tax rates between existing and new NGCC plants, which provides an important incentive to switch to cleaner natural gas generation. Moving from the CES ER to the TPS policy leads the net tax rates for all of the technologies, both those that get a net subsidy and those that face a net tax, to move (weakly) toward zero. This follows from the inclusion of the coal fleet in the covered entities under TPS, which lowers the marginal cost of emissions reductions and allows for a smaller carrot for nonemitting technologies and a smaller stick for emitting technologies. In the case of C Tax, there is no subsidy and carbon taxes are fully passed through in electricity prices to consumers, which means that a lower net tax rate on all emitting technologies is necessary to achieve the same level of emissions reductions (Fell and Linn forthcoming).

The differences in the subsidy results for NGCC units between the CES Tech and the CES ER policies result from a combination of factors. First, the CES Tech scenario credits only combined cycle units and does so at a rate of 0.5 credit per MWh to all generation from NGCC units except those with CCS, which earn 0.9 credit for each MWh of generation. The CES ER scenario credits all natural gas generation, including generation from natural gas boilers and from combustion turbines (CTs) that have an emissions rate below the reference rate for crediting, and the crediting rate varies with emissions rate. As a consequence, the average crediting rate across all natural gas generation is slightly below 0.5 credit per MWh under CES Tech through 2020. After 2020, when some NGCC with CCS investments occur, the average crediting rate actually climbs above 0.5, reaching 0.58 credit per MWh in 2035. Under the CES ER scenario, the average crediting rate across all natural gas units is typically 0.5 or higher and is generally higher than that under the CES Tech scenario through 2027. In 2035, the average crediting rate is actually slightly higher under CES Tech than under CES ER. The implications of these differences are manifest in Table 3, which summarizes the ultimate differences in incentives for switching between technology classes under the different scenarios.

Table 3. Tax and Subsidy Rates by Policy and Technology

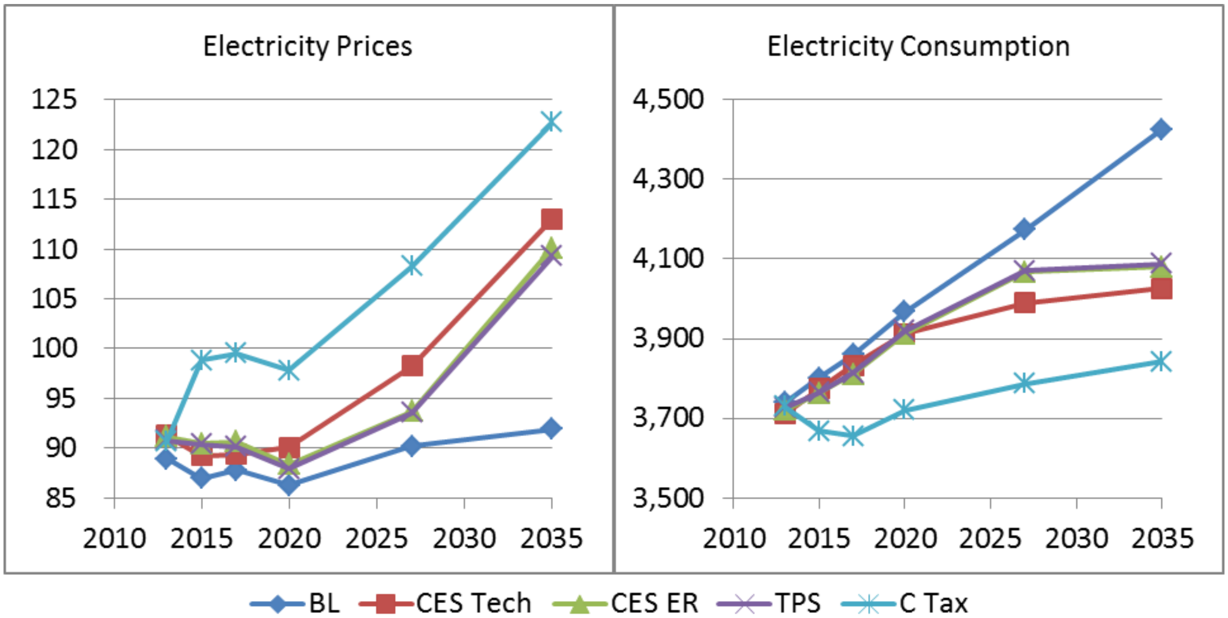
2020	$/MWh	CES Tech	CES ER	TPS	C Tax
Non-emitting	Tax	20	18	0	0
	Subsidy	38	34	12	0
	Net Tax	**-18**	**-16**	**-12**	**0**
Coal Boilers	Tax	20	18	27	21
	Subsidy	0	0	12	0
	Net Tax	**20**	**18**	**14**	**21**
Existing NGCC	Tax	20	18	12	9
	Subsidy	19	17	12	0
	Net Tax	**1**	**1**	**0**	**9**
New NGCC	Tax	20	18	10	8
	Subsidy	19	20	12	0
	Net Tax	**1**	**-2**	**-2**	**8**
2035	**$/MWh**	**CES Tech**	**CES ER**	**TPS**	**C Tax**
Non-emitting	Tax	60	60	0	0
	Subsidy	78	79	18	0
	Net Tax	**-18**	**-18**	**-18**	**0**
Coal Boilers	Tax	60	60	73	62
	Subsidy	0	0	18	0
	Net Tax	**60**	**60**	**55**	**62**
Existing NGCC	Tax	60	60	36	30
	Subsidy	39	40	18	0
	Net Tax	**21**	**21**	**18**	**30**
New NGCC	Tax	60	60	30	25
	Subsidy	39	46	18	0
	Net Tax	**21**	**14**	**12**	**25**

Electricity Prices and Demand

The left-hand panel of Figure 2 displays average electricity prices. With the exception of C Tax, the influence of the policies on electricity prices is fairly small through 2020, with price impacts of less than 3 percent in all cases. In 2020 and thereafter, the price effects of the policies increase, reflecting investment costs needed for policy compliance. By 2035, the price impact is roughly $20 per MWh for the nontax scenarios, just above for CES Tech, just below for the other two. In contrast, C Tax has a significant impact on electricity prices, beginning as soon as the tax takes effect in 2015 and increasing more dramatically after 2020. By 2035, retail prices are 33 percent above baseline levels. The C Tax scenario has no subsidy component, so more of the cost of the policy is passed on to consumers in the form of higher electricity prices than under the other scenarios.

The effects of the policies on electricity demand are displayed in the right-hand panel of Figure 2. They are the mirror image of the price results.

Figure 2. National Average Retail Electricity Prices ($/MWh) and Consumption (BkWh)



Generation Mix and Heat Rates

Emissions reductions under the different climate policies analyzed here come from changing the technologies and fuels used to generate electricity. The differences are manifest in terms of investments to improve heat rates at existing coal plants, changes in investment and dispatch within and between technology classes, and reductions in demand for electricity. The relative contributions of these margins vary across policies and over time. Figure 3 provides a snapshot for 2020, comparing the policies on generation mix and average heat rates for selected technology classes. The left-hand axis corresponds with the stacked bars; they show generation by technology class. The right-hand axis corresponds with the lines; they show fleet-average heat rates for three technology classes: existing steam coal in blue diamonds, existing NGCC in green squares, and new NGCC in gray triangles.

In 2020, all of the policies lead to a substantial reduction in electricity produced by existing coal boilers. None of the policies induce a meaningful increment of nonemitting (nuclear or renewable) generation by 2020. The CES Tech policy treats existing and new NGCC plants identically (in the same technology class), even though modern NGCCs are more efficient than the existing fleet, shown by the lines in the figure. This leads to roughly proportional increases in generation from both classes under the policy. So CES Tech induces an emissions-reducing substitution between coal and NGCC but fails to induce the like substitution between efficient new NGCCs and less efficient existing ones or substitution within the existing natural gas fleet from less efficient to more efficient units. There is a slight increase in the average heat rate of both existing and new NGCCs under CES Tech as total NGCC utilization increases without substitution between the efficient and inefficient parts of the fleet. The CES ER policy recognizes emissions rate differences within technology classes, inducing a substitution relative to CES Tech from generation by inefficient existing NGCCs to generation by new ones.

The TPS policy extends the scope of the production subsidy inherent under the CES ER policy to the coal boiler fleet, allowing any cost-effective reductions available due to heterogeneity in coal fleet emissions rate to be harvested. The result is a marked improvement in the efficiency of the existing coal boiler fleet. The crediting of coal units under TPS, which are not credited under either CES policy, leads to an increase in generation from coal under TPS relative to CES ER in 2020. The C Tax scenario lacks a subsidy component, so the electricity price and demand effects of this policy are greater than under the others. The heights of the stacked bars in Figure 3 reveal this demand effect, and it is generation by new NGCC that is offset by lower demand. The increase in coal generation between TPS and C Tax occurs because the opportunity cost of incremental CO_2 emissions is lower with C Tax than under the TPS scenario. Because it includes an output subsidy, TPS results in a higher price for carbon than under a carbon tax that achieves the same level of emissions reduction.

Figure 4 reports the same outputs as Figure 3, but for 2035. The relative effects of the different policies in 2020 are also found in 2035 and are often more pronounced. In addition, by 2035, electricity prices under all the policies are well above baseline, and the corresponding demand effect is shown as the change in height of the stacked bars. Also, by 2035, the opportunity cost of carbon emissions is high enough to induce incremental investments in nonemitting technologies, nuclear and wind. Moving to the right across the scenarios in the figure, penetration by nonemitting sources declines as the opportunity cost of emissions declines with increased policy efficiency.

Figure 3. Generation and Heat Rate in 2020

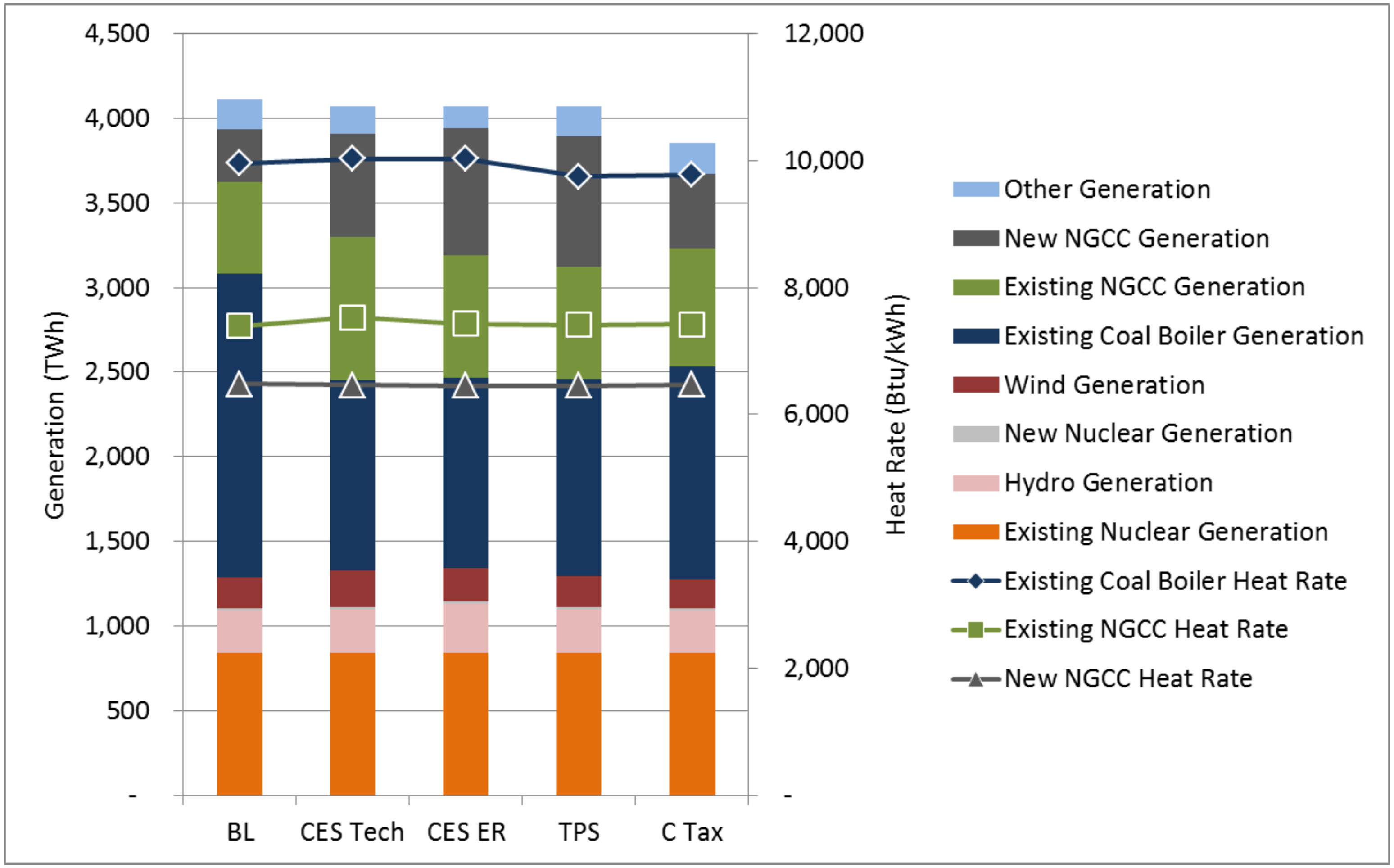
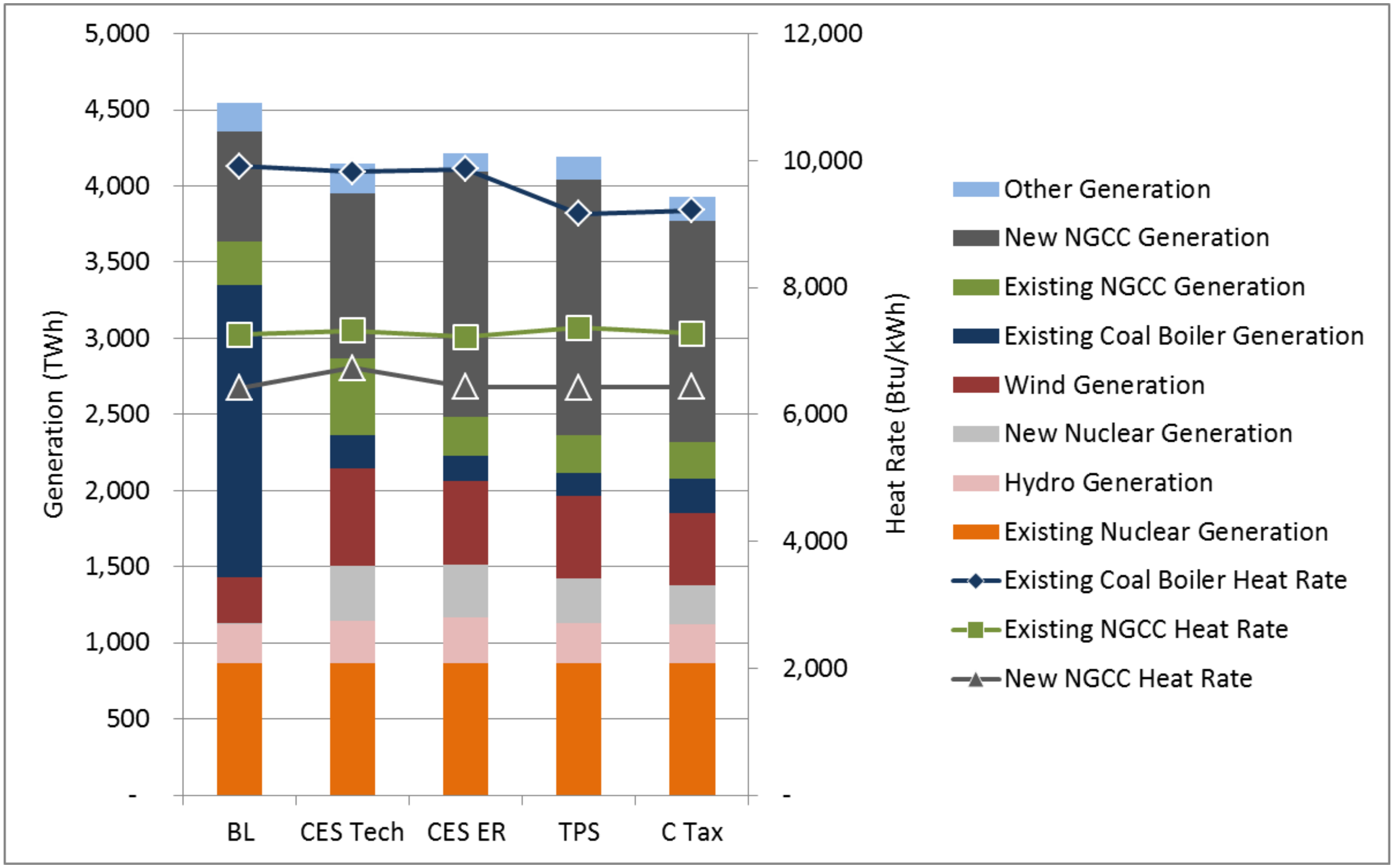


Figure 4. Generation and Heat Rate in 2035



Sources of Emissions Reductions

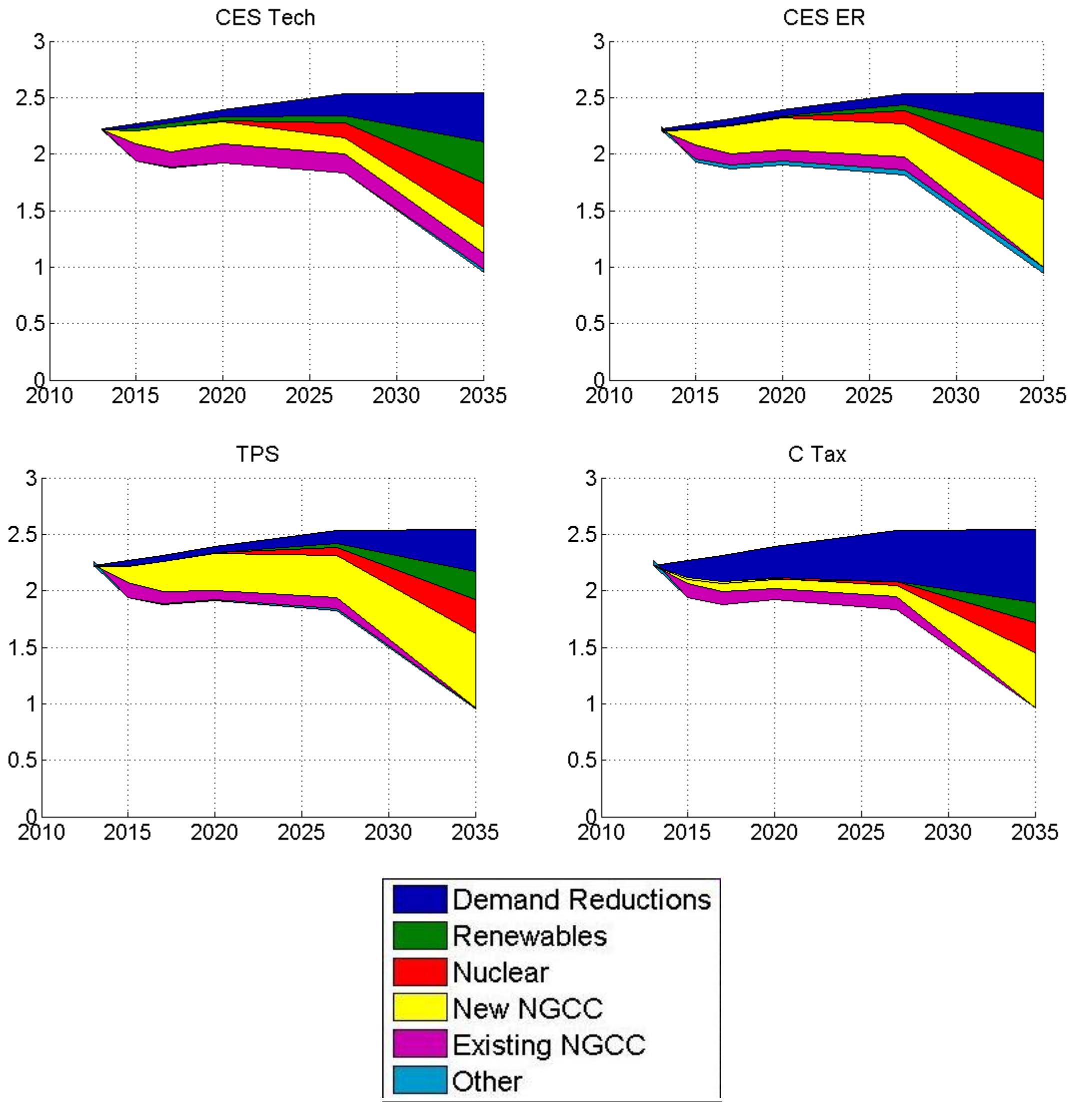
The sources of the emissions reductions under the different policies vary depending on the relative incentives for generation with the different technologies. Figure 5 shows the relative contributions to emissions reductions of shifting sources of supply and reduced demand under the different policies.[20] In each case, the top line of the shaded area shows the CO_2 emissions trajectory under the baseline, and the bottom line is the emissions trajectory under the policy. The panels in this figure tell a story similar to that of the stacked bars in Figures 3 and 4, but in emissions space instead of generation space.

The graphs show that the CES Tech policy initially achieves emissions reductions largely through substitution of natural gas for coal, and over time demand reduction and growth in renewables and nuclear generation contribute more, which is consistent with the growth in the clean energy target and the increase in electricity price effects of the policy after 2025 as shown in Figure 2. Under CES Tech, growth in generation from both existing and new NGCC plants contributes to emissions reductions, and the relative contributions of each do not change much over time. Under the CES ER policy, an even greater share of emissions reductions comes from substitution of gas for coal, and most of that contribution is attributable to new NGCC units. Nonemitting sources and demand reductions contribute less to overall emissions reductions under CES ER. The TPS and CES ER scenarios have very similar contributions from different sources to overall emissions reductions, with a slightly larger ultimate contribution from fuel switching to new gas units under TPS. The lion’s share of emissions reductions under C Tax comes from reduced demand, with the next largest share from higher natural gas generation, initially from a mix of new and existing units, but ultimately from new units exclusively. Under

[20] The attribution of emissions reductions to different sources in each simulation year depends on two sets of generators: those that reduce their production and those that increase. Which category a particular type of generator falls into can vary over time and by policy scenario. Those that increase will have some emissions reduction attributed. For each generator type (nuclear, renewables, sometimes natural gas) that increases generation, the share of emissions reductions attributable to that increase is equal to the average emissions intensity of generation displaced by the policy less the emissions intensity of the increased generation multiplied by the amount of increased generation. The share of emissions reductions attributable to lower demand is the product of the change in demand times average emissions intensity of generation displaced by the policy. A formal algebraic derivation of the emissions change attribution is presented in Appendix 3.

the C Tax scenario, increased generation from nuclear and renewables contributes in only small ways to emissions reductions, and this happens primarily after 2025.

Figure 5. Sources of CO_2 Emissions Reductions (billion short tons)[21]



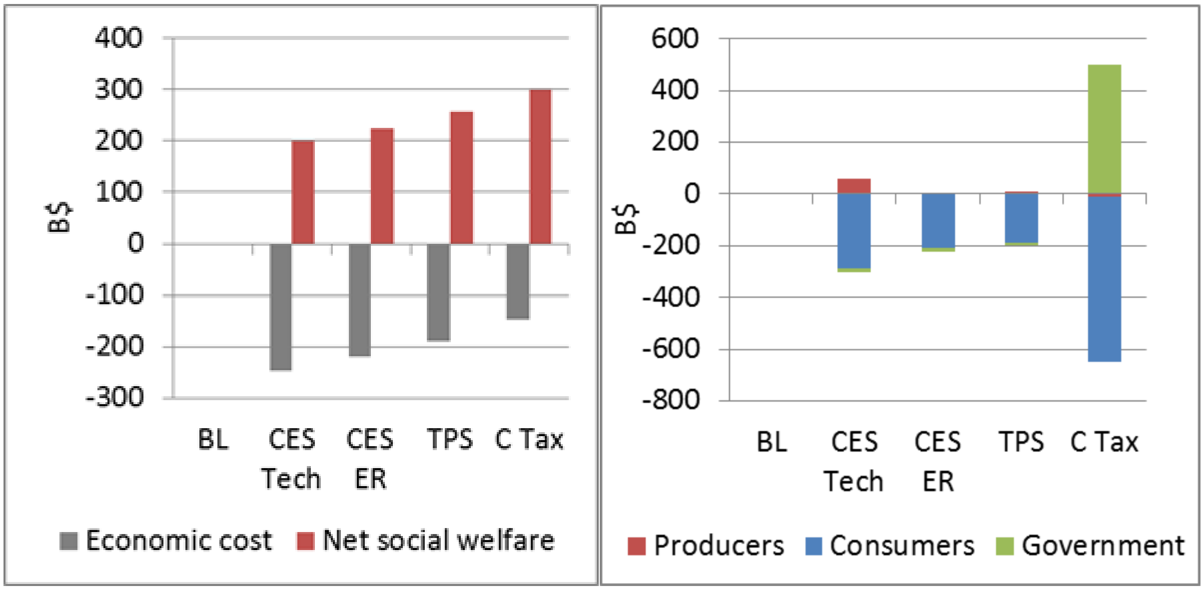
[21] The Other category includes changes in generation from a collection of technologies including oil and gas turbines and boilers, geothermal, municipal solid waste, IGCC coal and existing combined heat and power units.

Welfare

We evaluate the welfare consequences of these policies in two different ways. First we focus on cost-effectiveness, comparing the policies, which yield identical CO_2 emissions outcomes, in terms of present discounted economic cost impacts through 2035, both in total and by components of consumer, producer, and government surplus. Then, using midlevel estimates of the social cost of carbon (IWG 2013), we calculate the present discounted value of avoided CO_2 emissions and combine these with the economic costs to yield net social welfare effects. Welfare changes are measured on a cumulative present discounted value basis through 2035, with economic costs discounted back to 2013 at 5 percent per year and carbon benefits discounted at 3 percent per year, consistent with the discount rate used to develop the midlevel social cost of carbon estimate that we adopt. Total cumulative economic costs and net welfare impacts of the policies are displayed in the left-hand panel of Figure 6. The right-hand panel shows the three components of economic cost.

The left-hand panel of Figure 6 shows that C Tax has the lowest economic cost among the climate policies. CES Tech is most costly, with present discounted economic losses over 22 years of about $247 billion. The treatment of emissions rate differences within technology classes under the CES ER scenario reduces total discounted cumulative economic losses to $214 billion. Economic losses shrink further, to $188 billion, under the TPS policy, which extends the scope of differentiated incentives to the coal fleet by rewarding changes in dispatch between higher- and lower-emitting coal units. Extending flexibility to the demand margin under the C Tax scenario, which reaches every margin available for emissions reductions, reduces economic losses to $147 billion. The economic losses under C Tax are roughly 60 percent of the losses under the CES Tech policy, for equivalent climate outcomes.

Figure 6. Net Present Value of Cumulative Welfare through 2035



The three components of economic cost—producers, consumers, and government surplus—are broken out in the right-hand panel of Figure 6 (note the different scaling of this graph), revealing that consumers bear the greatest share of total cost of the climate policies[22]. Producers stand to gain slightly under CES Tech, because it ultimately leads to higher electricity prices and higher net subsidies to clean generation, but are otherwise virtually indifferent to the policies. Reduced welfare for consumers follows directly from electricity price increases. Consumers are worst off under a carbon tax, but a sufficient amount of the cost to consumers under the C Tax scenario is made up by government to make it the least costly in welfare terms of the climate policies modeled here. Government surplus falls slightly under the other policies, as lower electricity demand reduces electricity tax revenues to local and state governments.

To evaluate the relationship between the economic costs of the policies and their climate benefits, we adopt the midlevel social cost of carbon estimates (those associated with the 3 percent discount rate) developed by the federal Interagency Working Group (IWG 2010, 2013) to calculate the benefits of avoided CO_2 emissions. The present discounted value of those

[22] Surplus in other markets such as fuel markets is not measured.

benefits (using a 3 percent discount rate to discount back to 2013) is $446 billion and is identical for all of the policy scenarios because they have identical emissions paths. Combining discounted climate benefits with the estimates of economic costs yields net social welfare impacts, shown in the red bars on the left-hand side of Figure 6. This graph reveals that all of the policies have substantial positive net discounted cumulative benefits of between $200 billion and $300 billion, and the benefits are roughly 50 percent higher under the C Tax than under the CES Tech policy.[23]

Conclusions

Achieving the US long-run national greenhouse gas emissions goal of 83 percent below 2005 levels by 2050 will require a nearly wholesale shift from fossil-fueled electricity supply to nonemitting sources of generation over the next 35 years. Policy will be necessary to bring about that transition, and finding a policy that can do so cost-effectively is crucial to maintaining economic well-being while striving to achieve our climate goals. A clean energy standard (CES) has been proposed as a potentially effective way to facilitate the transition to a clean electricity sector. By focusing on the clean generation side of the equation, the CES has the appearance of being more of a carrot than a stick approach to reducing the climate impacts of the electricity sector. A CES is broader based than a narrowly focused renewable portfolio standard and thus has higher emissions reduction potential and lower cost per ton of CO_2 abated (Palmer et al. 2010). A CES policy also has political appeal because of its relatively small effect on average retail electricity prices, especially in the near term. This distinguishes a CES from a carbon tax, which imposes substantially higher costs on electricity consumers from the outset. Nonetheless, a carbon tax has attracted attention in tax policy circles because of its potential to raise revenue and address federal fiscal challenges.

While all of the approaches studied here are market-based instruments that offer significant flexibility, from a welfare perspective, a technology-based CES (CES Tech) is the

[23] If the climate benefits calculated using the SCC rates based on 3 percent are discounted back to 2013 using a 5 percent instead of a 3 percent discount rate, the discounted climate benefits of all the policies falls to $315 billion, the net social welfare under each policy would be reduced by approximately $130 billion, and the difference in net social welfare across the policies widens significantly, with net social welfare under the C Tax scenario roughly 100 percent higher than under the CES Tech scenario. If other environmental co-benefits (such as reduced mortality from reduce SO_2 emissions) were included they would increase the estimate of the net benefit of a climate policy (Burtraw et al. 2014).

least cost-effective policy instrument among the group because it is the bluntest. CES Tech fails to harvest some economic CO_2 emissions reductions because it misses opportunities to reduce emissions along three important margins: emissions rate heterogeneity within the NGCC fleet, emissions rate heterogeneity within the coal boiler fleet, and electricity demand reductions. A carbon tax (or equivalently in a deterministic world, a tradable cap) picks up all three margins, discouraging carbon-intensive generation of all forms and encouraging efficiency in electricity demand. The other scenarios studied here are in between CES Tech and a carbon tax (C Tax) in welfare terms because they pick up a subset of the margins discussed above.

Specifically, the efficiency of a CES is improved when generation from clean technologies is credited on the basis of emissions rates instead of technology type—that is, shifting from CES Tech to CES ER. When the reference emissions rate in the CES ER policy is set at a level to credit all generators except coal boilers, as modeled here, the policy will encourage generation from and investment in the most efficient NGCC generators, but it provides no incentive to use coal more efficiently. Moving from CES ER to the TPS policy that credits all generators will encourage greater use of coal units (relative to NGCC) and redispatch of coal units, as well as investments in improvements in coal-fired efficiency at existing coal plants, which combined provide low-cost emissions reductions. Demand reductions can be harvested by removing the subsidy component of the policy and allowing retail electricity prices to rise by introducing a carbon tax.

The model simulation results presented here show that for the level of CO_2 emissions reductions achieved under a CES Tech policy, a C Tax policy is 40 percent more cost-effective in terms of cumulative economic welfare costs than the CES Tech policy. Adding greater flexibility to the CES through crediting on the basis of emissions rate – the CES ER policy – lowers discounted welfare cost by roughly 13 percent. The TPS policy is roughly 25 percent less costly than CES Tech. Despite the nontrivial differences in cost-effectiveness, all of these policies are net winners in a benefit–cost trade-off when the value of CO_2 emissions reductions is added to the mix.

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Appendix 1. Overview of Results

Table A1. Overview of Results for 2020

	BL	CES Tech	CES ER	TPS	C Tax
Electricity Price ($/MWh)	86	90	88	88	98
Consumption (TWh)	3,968	3,912	3,910	3,919	3,720
Generation (TWh)					
Coal					
Boilers	1,873	1,193	1,202	1,243	1,344
IGCC	4	4	4	4	4
Natural Gas	871	1,460	1,482	1,450	1,149
Natural Gas					
Existing CC	545	848	723	669	697
New CC	310	606	750	770	438
Other	16	5	9	10	13
Nuclear	847	855	854	854	853
Wind	183	217	193	178	164
Hydro	255	258	291	260	255
Other	98	87	53	92	98
Total	4,131	4,073	4,079	4,081	3,866
Nameplate Capacity (GW)					
Coal					
Boilers	334	277	257	268	277
IGCC	1	1	1	1	1
Natural Gas	422	452	472	478	429
Natural Gas					
Existing CC	196	197	194	195	193
New CC	47	88	108	111	63
Other	180	167	170	171	173
Nuclear	111	112	111	111	111
Wind	64	77	69	64	58
Hydro	96	96	96	96	96
Other	55	54	52	52	51
Total	1,083	1,068	1,057	1,069	1,023
CO_2 Tax Rate/Allowance Price ($/Ton)	-	-	-	27	21
Clean Energy Credit Price ($/MWh)	-	38	34	-	-
Annual CO_2 Emissions (B Tons)	2.4	1.9	1.9	1.9	1.9
Cumulative CO_2 Emissions (B Tons)	18.4	15.8	15.8	15.8	15.8
Annual Environmental Surplus (B$)	-	14	14	14	14
Cumulative NPV Environmental Surplus (B$)	-	74	73	74	74
Annual Economic Surplus (B$)	-	(6)	(9)	(6)	(3)
Cumulative NPV Economic Surplus (B$)	-	(9)	(35)	(21)	(24)
Annual Tax Revenue (B$)	-	-	-	-	27
Cumulative NPV Tax Revenue (B$)	-	-	-	-	175

Notes: Cumulative values cover 2013–2035; 2009$. CC = combined cycle, GW = gigawatt, IGCC = integrated gasification combined cycle, NPV = net present value, TWh = terawatt hour, Ton = short ton.

Table A2. Overview of Results for 2035

	BL	CES Tech	CES ER	TPS	C Tax
Electricity Price ($/MWh)	92	113	110	109	123
Consumption (TWh)	4,427	4,026	4,079	4,087	3,841
Generation (TWh)					
Coal					
Boilers	2,005	243	187	183	276
IGCC	4	114	70	50	21
Natural Gas	1,011	1,588	1,869	1,929	1,700
Natural Gas					
Existing CC	281	506	258	241	244
New CC	723	1,081	1,608	1,685	1,453
Other	7	1	3	3	3
Nuclear	874	1,229	1,206	1,161	1,125
Wind	302	638	554	541	471
Hydro	255	278	305	265	255
Other	102	60	30	67	81
Total	4,553	4,149	4,220	4,196	3,930
Nameplate Capacity (GW)					
Coal					
Boilers	334	174	141	134	153
IGCC	1	15	9	7	3
Natural Gas	517	500	564	590	531
Natural Gas					
Existing CC	196	193	184	189	183
New CC	132	157	230	247	210
Other	189	150	150	153	138
Nuclear	111	156	153	147	143
Wind	107	236	200	195	171
Hydro	96	96	96	96	96
Other	55	48	44	41	44
Total	1,219	1,224	1,207	1,209	1,140
CO_2 Tax Rate/Allowance Price ($/Ton)	-	-	-	80	66
Clean Energy Credit Price ($/MWh)	-	78	79	-	-
Annual CO_2 Emissions (B Tons)	2.5	1.0	1.0	1.0	1.0
Cumulative CO_2 Emissions (B Tons)	56.1	39.6	39.6	39.6	39.7
Annual Environmental Surplus (B$)	-	39	39	39	39
Cumulative NPV Environmental Surplus (B$)	-	446	445	446	446
Annual Economic Surplus (B$)	-	(81)	(73)	(70)	(65)
Cumulative NPV Economic Surplus (B$)	-	(247)	(220)	(188)	(148)
Annual Tax Revenue (B$)	-	-	-	-	20
Cumulative NPV Tax Revenue (B$)	-	-	-	-	584

Notes: Cumulative values cover 2013–2035; 2009$. CC = combined cycle, GW = gigawatt, IGCC = integrated gasification combined cycle, NPV = net present value, TWh = terawatt hour, Ton = short ton.

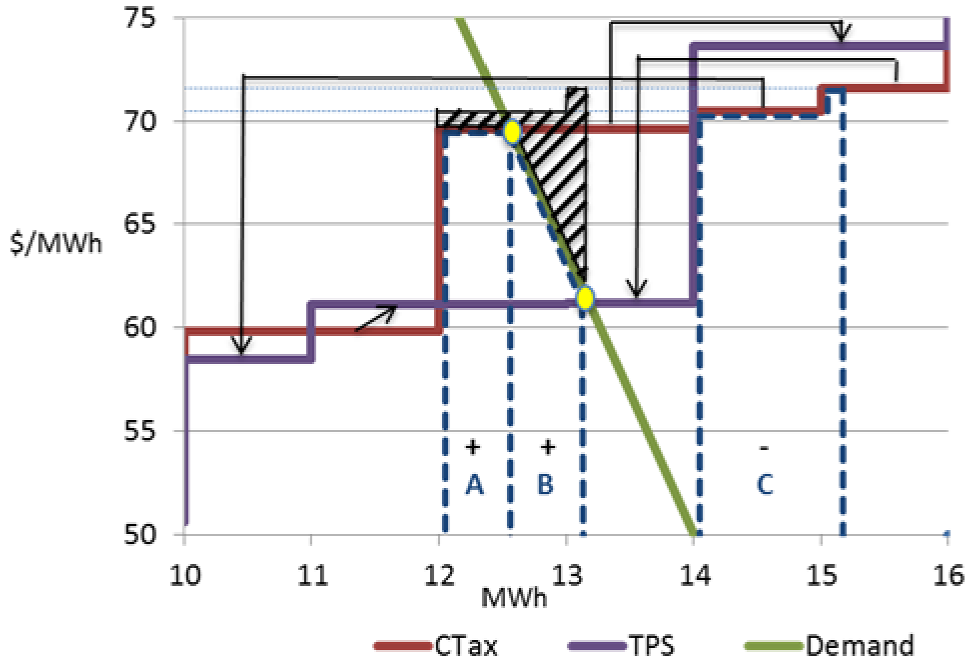
Appendix 2. Welfare Illustration

The economic welfare impacts of the different policies are illustrated by incorporating the tax and subsidy components of the policies into a toy model of electricity supply and demand. The welfare losses from each policy transition stem from the redispatch of generators away from the socially optimal dispatch order under a C Tax scenario. Each successive policy transition away from C Tax induces a potential change in the dispatch order that is potentially more costly than its predecessor. The toy model includes representative non-emitting, coal, and natural gas generators. Heat rate and emissions rate heterogeneity is imposed within and between the coal and gas fleets.

Working backwards from the most efficient policy, C Tax, Figure A1 shows the supply and demand curves for the C Tax and TPS scenarios. Each supply curve shows the marginal cost of each generator including taxes and subsidies associated with the relevant policy. Emissions outcomes are held constant across the different market equilibria represented in the graphs. The figure zooms in on the marginal region of the curves in which only the fossil generators are relevant. There are 2 coal generators in this region, each with the capacity to produce 2 MWh of electricity, and they are the first two generators in the C Tax supply curve spanning the region from 10 to 14 MWh at costs of about 60 and 70 $/MWh. The 2 gas generators in the region both have the capacity to produce 1 MWh and are the last two generators in the C Tax supply curve, spanning the region from 14 to 16 MWh at costs just above $70/MWh.

For purposes of this welfare analysis we assume that the carbon tax rate is set to reflect the social cost of carbon emissions. As such, the C Tax supply curve is the full social cost curve in that it represents the sum of the private cost of power generation and the social cost of associated emissions. Any policy that causes a deviation from C Tax, in particular one that results in a dispatch order other than that under C Tax, will diminish social welfare. The arrows in Figure A1 show the redispatch of generators under TPS, the yellow dots mark the two equilibria, with C Tax equilibrium price just under $70/MWh and the TPS equilibrium just above $60/MWh. The key to unlocking the welfare effects is that the coal generator that is marginal under C Tax is not dispatched under TPS, while the two high cost gas generators that are not deployed under C Tax are dispatched under TPS. The three regions – A, B, C – each defined by the relevant dotted edge, show the changes in costs and benefits from implementing TPS instead of C Tax. Region A is the savings in social cost from not running the coal generator that is marginal under C Tax but moves beyond the margin under TPS. Region B shows increased benefits under TPS from higher electricity consumption because of the production subsidy that does not exist under C Tax. The welfare gains shown in regions A and B are more than offset by the extra social cost incurred by running the two gas generators (region C) that are idle under C Tax. The area of region C minus the areas of regions A and B is the welfare cost of TPS relative to C Tax, shown as the shaded area of the figure. Shifting region C to the left such that its left-hand border is contiguous with region A yields the shaded welfare loss.

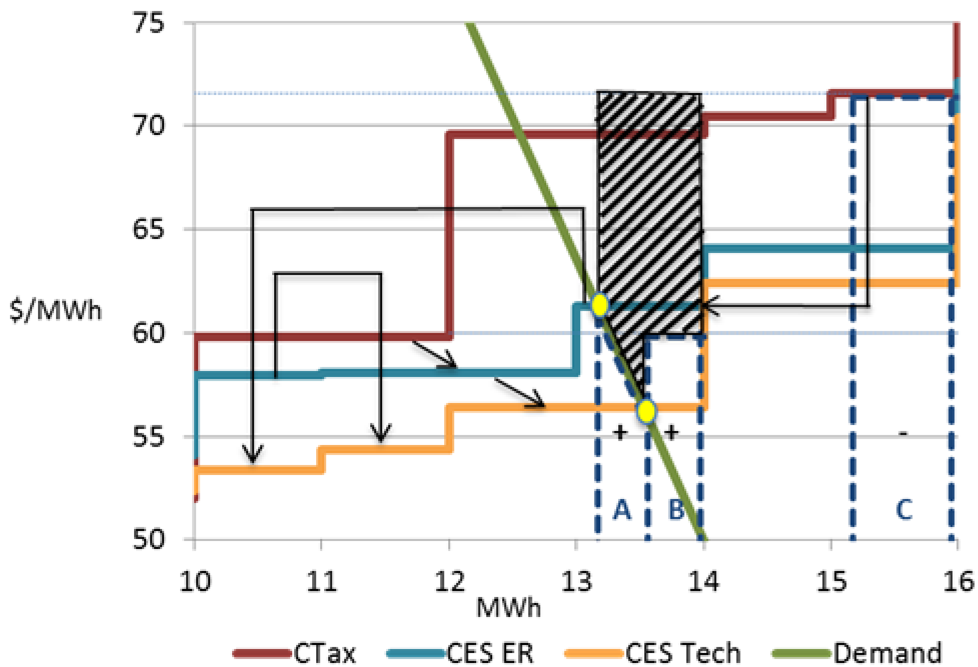
Figure A1. Economic Welfare: C Tax vs. TPS



As mentioned above in the analytical discussion, the welfare implication of the policy transition between TPS and CES ER is ambiguous and depends on the composition and character of the supply side. The parameters used in this illustration yield no difference in generator dispatch between the two policies with an equilibrium CES credit price that makes the marginal cost of the marginal gas generator under the CES ER equivalent to that under TPS. In the simulation results we find that TPS is welfare enhancing over CES ER, but in general that result need not hold. The welfare costs of CES ER are not shown here, since they are identical to those of TPS, but the CES ER supply curve is shown in Figure A2.

Figure A2 illustrates the welfare losses under CES Tech relative to CES ER. This figure is based on identical parameters as Figure A1, but shows outcomes under CES ER compared to CES Tech instead of C Tax compared to TPS. The differences follow from the differences in tax and subsidy rates under the policies. Again, generator redispatch away from the order under C Tax is the driver of welfare losses and the redispatch of plants in this region of the supply curves is shown by arrows moving from the red to the blue supply curves (for C Tax to CES ER) and from the blue to the gold curves (for CES ER to CES Tech). The key differences between CES ER and CES Tech are that the marginal gas generator under CES ER – from MWh 13 to 14 – becomes inframarginal under CES Tech, and the inframarginal coal generator under CES ER – from MWh 11 to 13 – becomes marginal under CES Tech. Region A in this figure shows increased benefits from CES Tech under lower prices and increased consumption[24]. Region B shows avoided social costs under CES Tech by not running the marginal coal plant at full capacity, as it is run under CES ER. Region C shows increased social costs by running at full capacity the gas plant that is marginal under CES ER. As in Figure A1, the difference between the losses and gains is the net welfare loss under CES Tech and is shown as the shaded region of the figure.

Figure A2. Economic Welfare: CES ER vs. CES Tech



[24] Note that CES Tech need not result in lower electricity prices than CES ER, and in the simulation results it does not. In this illustration, if the price under CES Tech rose beyond that under CES ER, then region B in Figure A2 would take the space of region A and exceed it, but still the area of region C would exceed regions A and B, yielding welfare loss under CES Tech.

Appendix 3. Derivation of Emissions Reduction Attribution

The attribution of emissions reductions to sources as a result of a policy comes from a simple arithmetic manipulation of an expression for changes in emissions between a policy scenario and the baseline. First, we define notation.

I = generator types ={Renewables, Nuclear, New NGCC, Existing NGCC, Coal, Other},

$\Delta X = X_{baseline} - X_{policy}$,

ΔE = change in total CO_2 emissions between baseline and policy,

Δe_i = change in emissions at generators of type $i \in I$,

ΔG = change in total generation,

Δg_i = change in generation at units of type $i \in I$,

$ER_i = \dfrac{\Delta e_i}{\Delta g_i}$ = emissions intensity (rate) of change in generation at units of type $i \in I$,

$J = \{i \in I : \Delta e_i < 0\}$ = generator types that reduce emissions,

$\overline{ER} = \dfrac{\sum_{j \in J} \Delta e_j}{\sum_{j \in J} \Delta g_j}$, average emissions intensity (rate) of changes in generation at units of type $j \in J$,

$K = \{i \in I : \Delta e_i \geq 0\}$ = generator types that do not reduce emissions.

The change in total emissions as a result of the policy is the sum of the changes in emissions at each generator type i, which in turn is the sum of changes in emissions at generators that reduce emissions (set *J*) and those that do not (set *K*). A similar identity applies to changes in generation as a result of the policy,

$$\Delta E = \sum_i \Delta e_i = \sum_{k \in K} \Delta e_k + \sum_{j \in J} \Delta e_j,$$
$$\Delta G = \sum_i \Delta g_i = \sum_{k \in K} \Delta g_k + \sum_{j \in J} \Delta g_j.$$

The two equations for ER_i and $\overline{ER}$ can be rewritten to yield changes in emissions at each unit in set *K* ($\Delta e_k = ER_k \cdot \Delta g_k$) and changes in emissions over the whole set of units of type *J* ($\sum_{j \in J} \Delta e_j = \overline{ER} \cdot \sum_{j \in J} \Delta g_j$). Substituting these two equations into the equation for ΔE yields

$$\Delta E = \sum_{k \in K} ER_k \cdot \Delta g_k + \overline{ER} \cdot \sum_{j \in J} \Delta g_j \; .$$

The equation for ΔG can be rearranged and substituted into this new expression for ΔE to yield

$$\Delta E = \sum_{k \in K} ER_k \cdot \Delta g_k + \overline{ER} \cdot \left(\sum_i \Delta g_i - \sum_{k \in K} \Delta g_k \right) = \sum_{k \in K} \left(ER_k - \overline{ER} \right) \cdot \Delta g_k + \overline{ER} \cdot \Delta G \, .$$

Each of the elements in the sum over K represents the change in emissions due to shifting generation from high-emitting sources that reduce emissions (generally coal) to each of the lower or non-emitting sources in K. The last term is the change in emissions due to the reduction in overall demand.