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Using Cap and Trade to Reduce Greenhouse Gas Emissions

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Lawrence H. Goulder*

1. Introduction

The emerging climate programs of several U.S. states employ cap and trade as a principal instrument for achieving GHG emissions reductions. It is a central feature of climate programs under the Eastern states' Regional Greenhouse Gas Initiative, California's planned climate effort, and the Western Climate Initiative involving six U.S. states and four Canadian provinces.

Cap and trade has also been the centerpiece of various climate policy discussions at the federal level. In June 2009, the U.S. House of Representatives passed the American Clean Energy and Security Act, a climate bill sponsored by representatives Henry Waxman (D-CA) and Ed Markey (D-MA). A federal cap-and-trade program was a central element of the Waxman-Markey bill. Various Senate committees proposed climate bills in 2010, as well, with cap and trade often a prominent feature of these proposals.

Cap and trade has three key components.

- First, the regulatory authority specifies the total quantity of allowances to be distributed in given periods to program participants. (For example, when implemented, allowances distributed in California's cap-and-trade program will cover about 85 percent of the state's GHG emissions.) Each allowance entitles the holder to a certain quantity of emissions of a given pollutant. In the case of a climate policy cap-and-trade program, an allowance entitles the holder to a certain quantity (usually expressed in metric tons) of

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GHGs in carbon dioxide equivalents (CO₂e). The number of issued allowances can decline over time; and in this case, overall emissions decline through time as well.

- Second, the regulatory authority distributes (puts into circulation) the emissions allowances. This can be done through free allocation, an auction, or some combination of the two.
- Third, the program allows participants to trade the emissions allowances. The ability to trade allowances is critical: it lies behind cap and trade's potential to achieve emissions reductions at a lower cost to emitters than would be possible under more traditional forms of regulation, such as mandated technologies or performance standards. Emitters will generally consider their costs of reducing emissions to the level required by their current holdings of allowances, and compare this with the market price of allowances. For emitters with especially high costs of emissions reductions, the market price will be less than this abatement cost. In this case, the emitter will benefit by purchasing additional allowances instead of taking on additional abatement cost. For emitters with especially low abatement costs, the market price will be greater than this cost. In this case, the emitter benefits by selling some of its allowances; although this obliges the emitter to reduce emissions even further, the proceeds from the sale will more than offset the additional abatement costs. Allowance trading thus results in more of the emissions reduction being undertaken by facilities that can do it most cheaply. Buyers and sellers both benefit, yet the trading leads to no change in overall emissions: the number of allowances in circulation has not changed.

This paper explores the economic impacts of introducing cap and trade at the national level in the United States. It considers the impacts on a range of economic variables, including gross domestic product (GDP), aggregate investment, and aggregate consumption. Much of the paper concentrates on results from the NEMS–RFF model,¹ although it also includes results from the Goulder Energy–Environment–Economy (E3) model.

Many specific designs of cap and trade are possible. Cap-and-trade programs can differ according to the stringency of the overall cap, the types of GHGs covered, and the sectors included in the program. They can also vary according to the ways in which emissions

¹ The National Energy Modeling System (NEMS) is a U.S. energy–economy model developed by the U.S. Energy Information Administration. NEMS–RFF is a version of NEMS developed by OnLocation Inc. for the Resources for the Future (RFF) modeling analysis.

allowances are initially allocated—through free allocation or by auctioning—and the use of revenues from an allowance auction (if applicable). In addition, programs can differ according to whether they allow for trading across time (referred to as *allowance banking and borrowing*) and whether they allow credit for *offsets* (emissions reductions resulting from certain activities taking place in sectors not covered by the program). This paper compares the outcomes under these alternative program designs with the aim of providing insights as to what forms of cap and trade might be particularly attractive.

The paper is organized as follows. The next section lists the design specifications within the Central case simulation for this analysis. Section 3 then compares outcomes under this simulation with those involving alternative assumptions about the availability of offsets and the stringency of the cap. Section 4 examines the implications of other design features, including the scope of the cap and the presence or absence of provisions for banking emissions allowances. Section 5 compares the efficiency costs of the various alternatives presented in sections 3 and 4. Section 6 then considers how economic impacts depend on the way in which any revenues from an allowance auction are returned to the economy. Section 7 discusses an alternative to cap and trade: a carbon tax. The final section offers conclusions and policy implications.

2. The Central Case Simulation

The Central case cap-and-trade simulation involves the following specifications.

- *The aggregate cap:* The time profile of the aggregate cap on covered sectors follows that of the Waxman-Markey bill, reducing covered emissions of all GHGs by 17 percent below 2005 levels by 2020 and 40 percent below 2005 levels by 2030.
- *GHGs covered:* The cap covers all GHGs.
- *Sectors covered:* The cap covers all major sectors (electric power, transportation, and industrial) as points of regulation. That is, emitters in each of these sectors are *compliance entities*—facilities that must submit emissions allowances to validate their emissions.²
- *Availability of offsets:* A limit of 0.5 billion tons applies to domestic offsets each year. A 0.5-billion-ton limit also applies to international offsets each year. (See below for definition of offsets.)

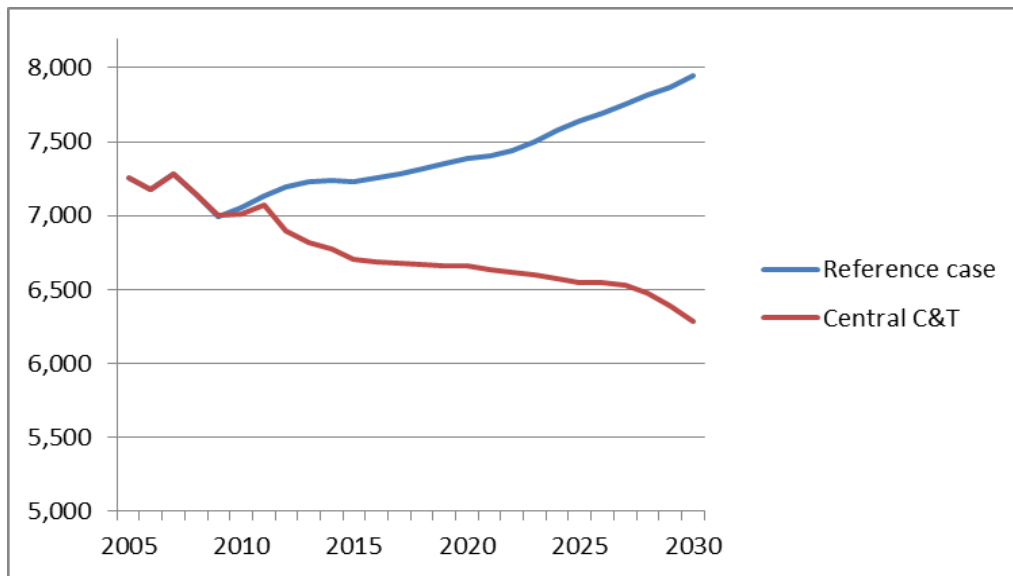
² Some policy proposals exempt firms in given sectors if emissions are below a certain threshold. No such exemptions apply in the simulations performed here.

- *Intertemporal allowance trading:* Banking and borrowing of allowances is allowed; bank balances must go to zero by 2030, meaning that by 2030 each compliance entity must have used up all previously banked allowances.
- *Method of allowance distribution:* All allowances are allocated through an auction.
- *Use of auction revenues:* Net revenues from the auction are recycled to the economy in a lump-sum fashion; this is consistent with revenues being returned as rebate checks.

While several of these features resemble those contained in the Waxman-Markey bill, many are different. For example, offset availability in the Central case is approximately half that of the Waxman-Markey bill. In addition, it is assumed that all allowances are auctioned, whereas the Waxman-Markey bill involves auctioning less than 35 percent of the allowances.

Figure 1 shows the GHG emissions under the Reference case³ and under the Central Cap-and-Trade (C&T) case simulation. These emissions are net of offsets. The time profile of reductions matches that specified under the Waxman-Markey bill.

Figure 1. Annual GHG Emissions in Millions of Metric Tons



Note: Central C&T figures are net of offsets.

³ The Reference case is basically the Energy Information Administration’s “*Annual Energy Outlook 2009 with Stimulus*” scenario, with enhanced Corporate Average Fuel Economy standards for vehicles.

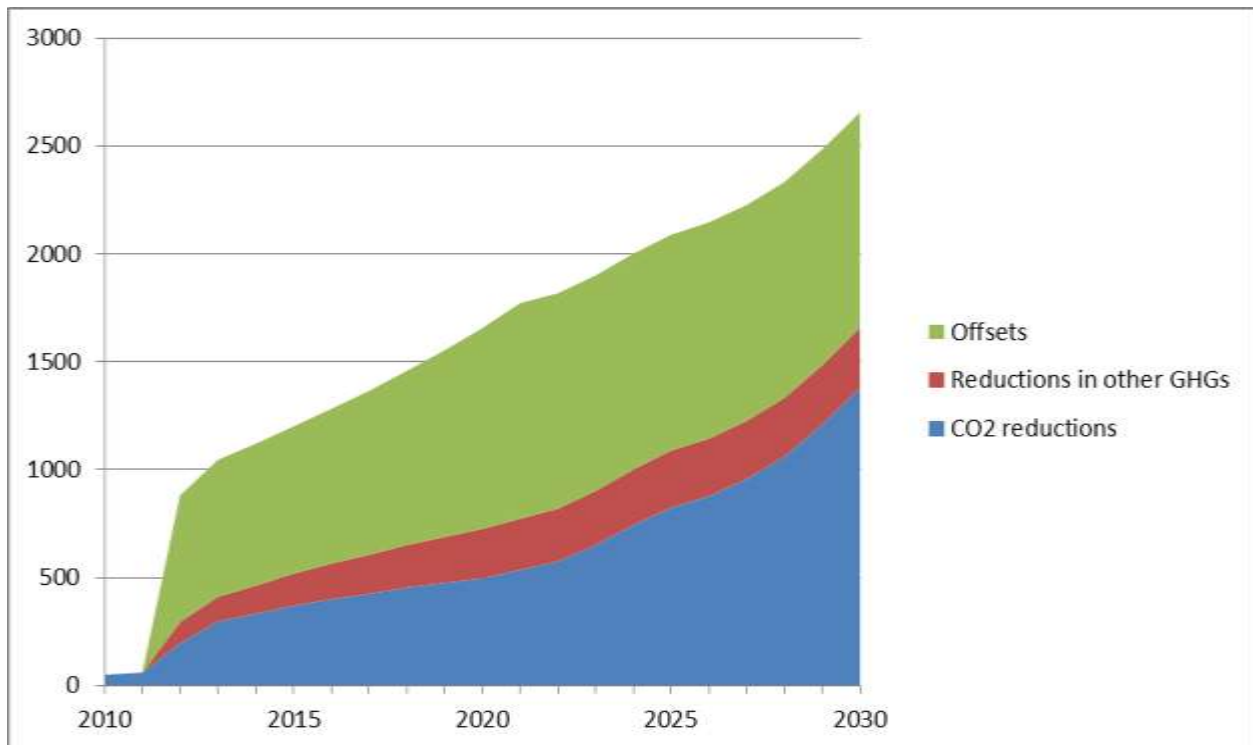
3. Significance of Offset Availability and Stringency of the Cap

A. Contributions of Offsets

One of the key policy decisions facing policymakers is how much, if at all, to include in the overall cap-and-trade policy provisions for offset credits. Such provisions would enable covered entities to gain emissions reduction credit(s) by financing a project outside of the covered sectors, that is deemed to cause a reduction in emissions or in atmospheric concentrations of GHGs. Suppose, for example, that the forestry sector is not a covered sector, and that the cap-and-trade system allows for offsets. In this case, the entity financing a project, such as afforestation, can be awarded certificates of emissions reductions to the extent that this project is deemed to have reduced the atmospheric accumulation of GHGs relative to what would otherwise have been the case. A covered entity (e.g., an industrial plant) can get credit for emissions reductions by purchasing such certificates.

Figure 2 shows, for the Central C&T case, the relative proportions of emissions reductions derived from covered-sector reductions in CO₂, covered-sector reductions in other GHGs, and offsets. Offsets clearly contribute a very large share of the overall reductions.

Figure 2. Sources of Emissions Reductions in Central C&T Case, in Millions of Metrics Tons



Offsets offer both advantages and difficulties. On the plus side, they extend the reach of a cap-and-trade program by introducing additional opportunities for reducing atmospheric concentrations of GHGs. This can help reduce the costs of achieving a given aggregate target for reducing emissions. On the minus side, offsets can threaten the environmental objectives of the program because some activities that generate credits for emissions reductions might not lead to true reductions. Entities get credits for emissions reductions when they finance a project in a noncovered sector that is deemed to have reduced emissions or concentrations relative to what would have happened in the absence of this particular financing. In many cases, it is difficult or impossible to discern whether the project involved would have been undertaken anyway (a concept known as *additionality*). If it would have been undertaken without the offset program, the project is actually a baseline activity. In this circumstance, the financing entity is getting credit for an emissions reduction when in fact there is no reduction relative to baseline. Several studies suggest that a large fraction of projects that qualify for offsets under the Kyoto Protocol's Clean Development Mechanism would in fact have been undertaken without this component of the Protocol.⁴

The Congressional Budget Office (2009) describes difficulties in ensuring the credibility and permanence of offsets and cautions that, as a result, offsets could at least partially undermine the ability of policies to achieve stated emissions goals.

Below I consider an alternative simulation with more conservative assumptions about the costs of supplying true offsets. This can be very important to the overall economic costs of cap and trade.

B. Allowance Prices

The more allowances a compliance entity owns, the less it must reduce emissions to be in compliance with the program. Firms generally are willing to pay a significant amount to lessen the extent to which they must reduce emissions, particularly if the cap-and-trade program calls for significant overall reductions.

The market price of allowances is an indicator of firms' marginal costs of GHG abatement. This is because, in theory at least, firms will reduce emissions up to the point where the marginal cost of further reductions (or abatement) equals the going market price of allowances. In doing so, a firm equates its marginal costs of abatement with its marginal benefit from abatement, where the latter is the avoided need to purchase another allowance. Other things

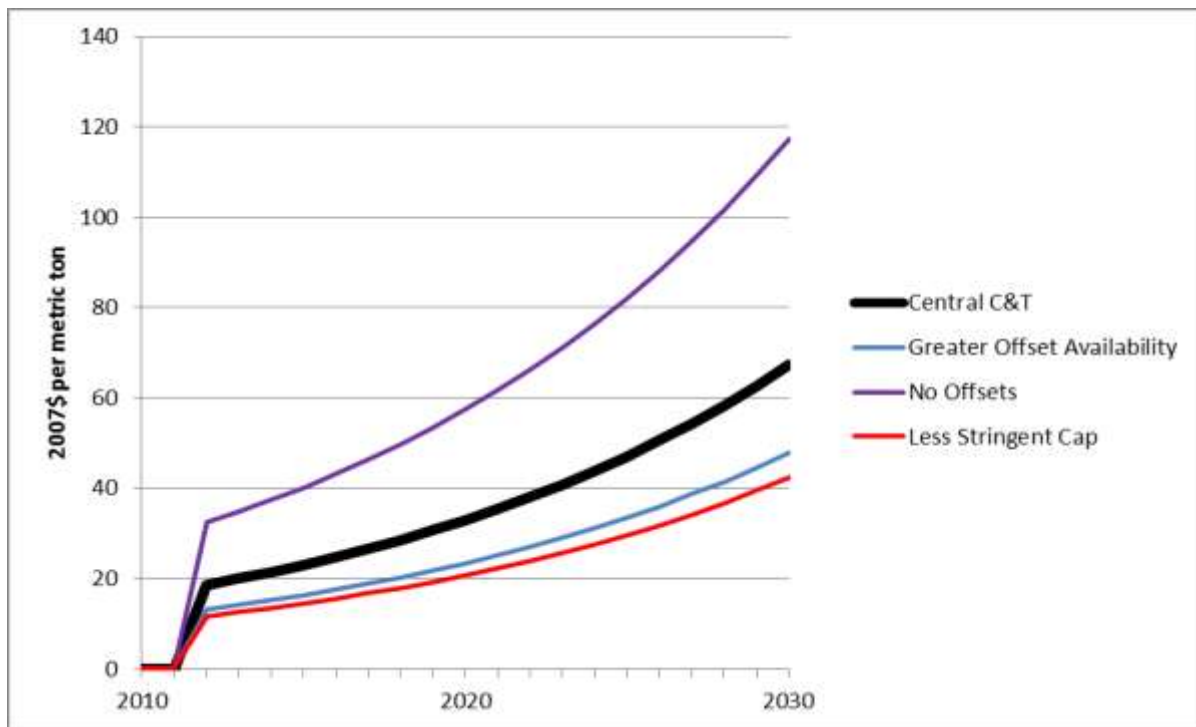
⁴ See, for example, Wara and Victor (2008).

being equal, a more stringent cap-and-trade policy leads to higher allowance prices because it compels firms to reduce emissions by a greater amount and thus leads to higher abatement costs.

Figure 3 shows the time profile of allowance prices from the NEMS–RFF model in the Central C&T case and three other cases, in which allowance prices rise through time in keeping with the increasing stringency of the policy over time.⁵ Technological progress mitigates, but does not eliminate, the price increase.

In this simulation, the NEMS–RFF model employs assumptions developed by the Energy Information Administration to arrive at a supply curve for offsets: the quantity of offsets available at given allowance prices. In addition, domestic offsets must not exceed a limit of 0.5 billion tons in any given year, and internationally supplied offsets must not exceed a limit of 0.5 billion tons in any given year.

Figure 3. Allowance Prices as a Function of Cap Stringency and Offset Availability



⁵ If the cap-and-trade system includes provisions for banking and borrowing, a greater overall stringency of the cap throughout the period during which banking and borrowing is permitted implies a higher time profile of allowance prices. In this case, the rate of increase of prices during this period reflects market interest rates. This reflects the fact that, under banking and borrowing, firms will bank or borrow allowances so as to equalize the present value of abatement costs in all periods; this implies that allowance prices rise at the rate of interest.

The purple and blue lines in Figure 3 indicate the time profile of allowance prices under alternative assumptions about the availability of offsets. In the No Offsets case, the allowance price path is about 70 percent above that of the Central case. A prohibition on offsets could result if policymakers concluded that nearly all projects requesting offset status would in fact be undertaken even without the financing that would come from covered entities under the cap-and-trade program. In the Greater Offset Availability case, the constraint on annual offsets is relaxed, so that up to two billion tons of offsets can be offered in any given year. In this case, the time profile of allowance prices is about one-third lower than in the Central C&T case. Thus, assumptions about the availability of offsets are very important.

The red line indicates the allowance price path from the Less Stringent Cap simulation. In this case, the required reductions in each year are two-thirds the magnitude of the required reductions of the Central C&T case, and the allowance price path is about two-thirds the height of the time path from the Central C&T case. Note that the relaxed cap has the same implication for allowance prices as does introducing provisions for offsets. To the extent that offsets lead to real reductions, their introduction has an advantage over relaxing the cap because they lead to lower emissions.

C. Economywide Impacts

Figure 4. Impacts on GDP as a Function of Cap Stringency and Offset Availability (Percentage Change from Reference Case)

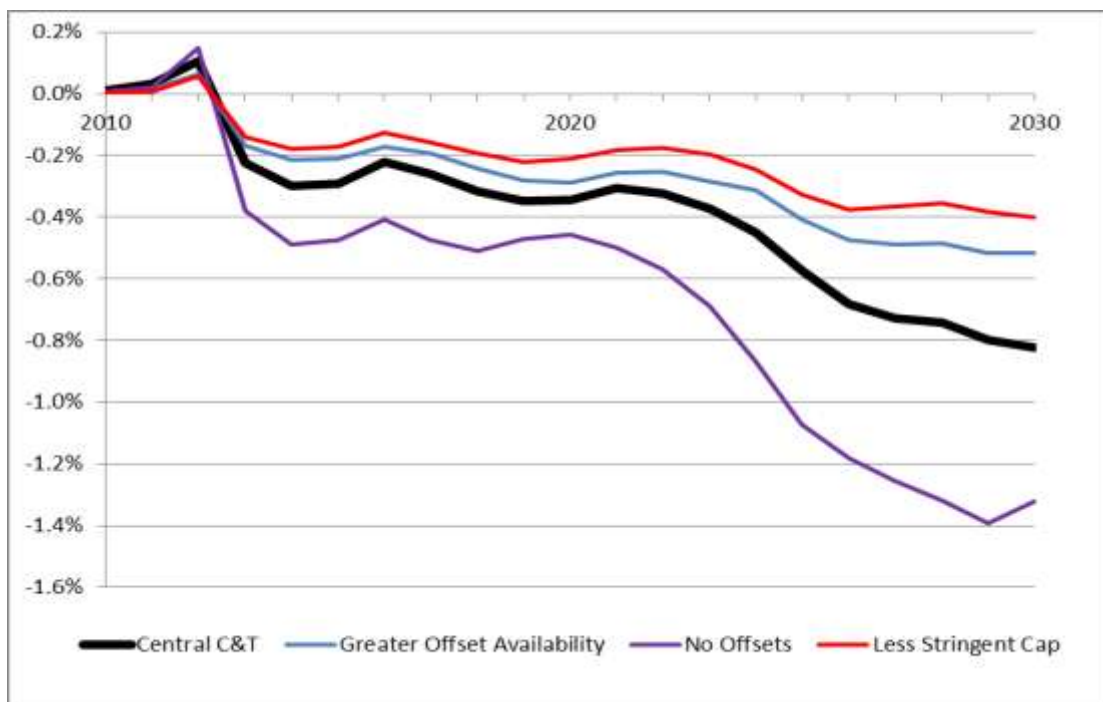
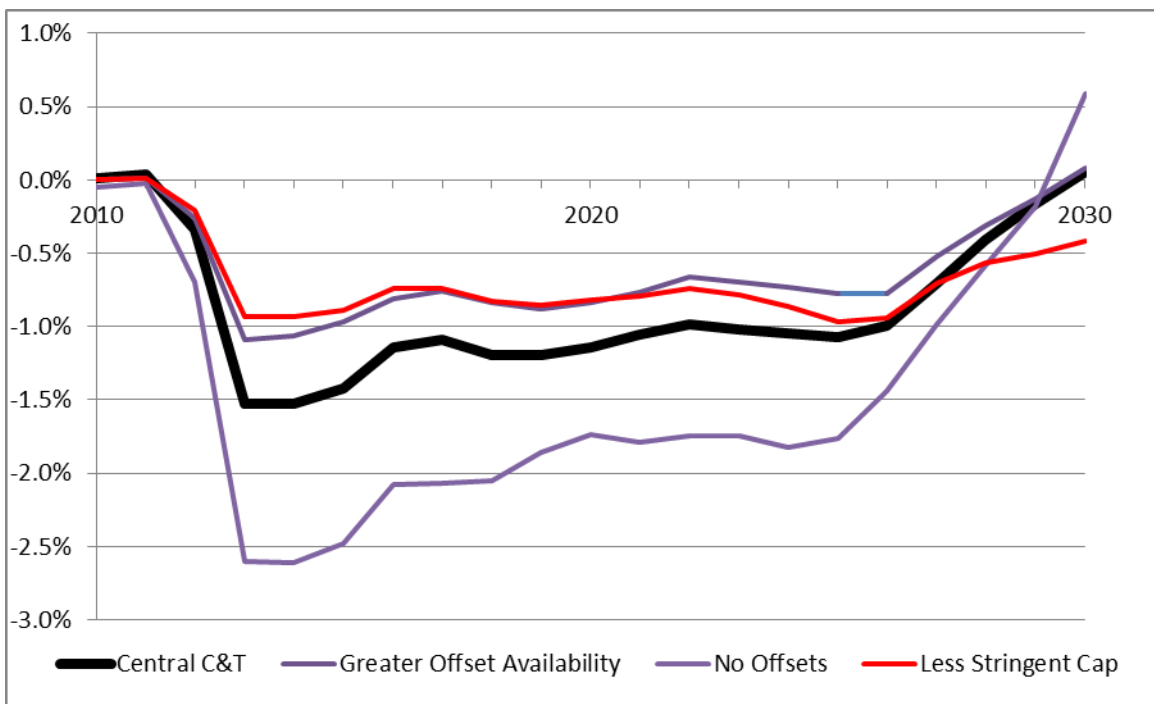


Figure 4 shows the time profiles of the GDP impacts under various cap-and-trade scenarios. The GDP costs increase through time, reflecting the increasing stringency of the cap. Technological progress helps dampen the increase in GDP costs. GDP costs are 1.5 to 2 times greater in the No Offsets case, whereas more liberal availability of offsets reduces the GDP costs by a third or more. Making the cap one-third less stringent leads to a reduction of about 50 percent in GDP costs, indicating that the increase in GDP costs is more than would be proportional to the stringency of the cap.

Figure 5. Investment Impacts as a Function of Cap Stringency and Offset Availability (Percentage Changes from Reference Case)

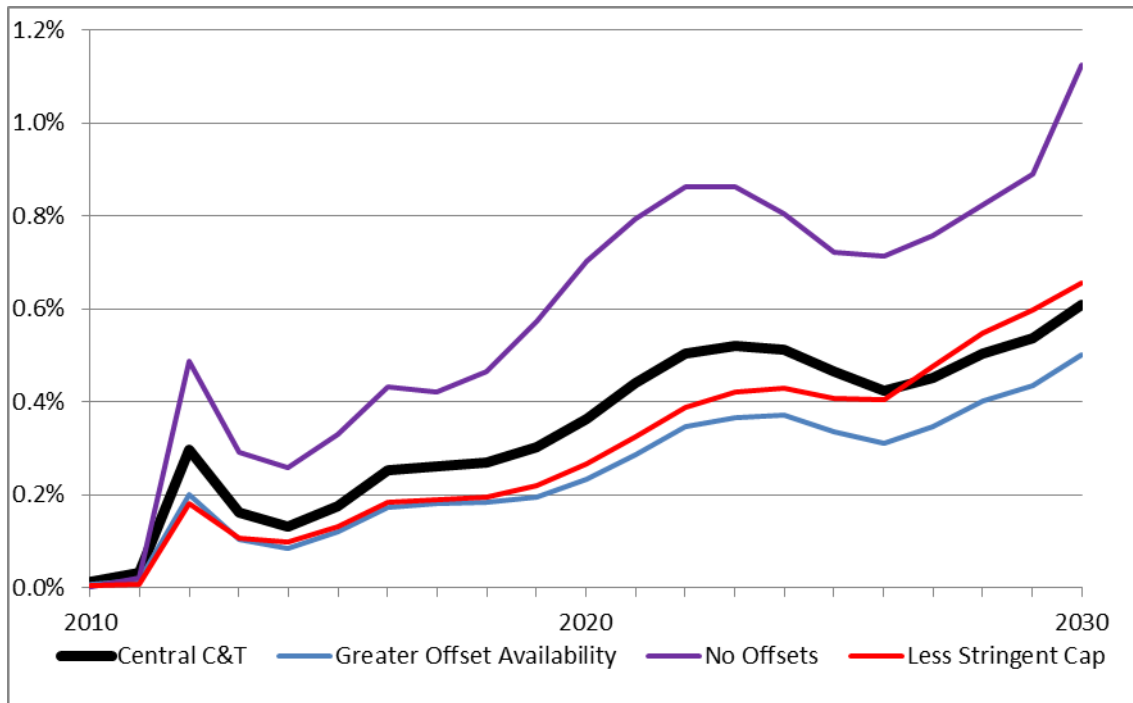


Figures 5 and 6 show the impacts on aggregate investment and consumption, respectively. Cap and trade effectively makes fossil fuels more expensive because firms must submit emissions allowances in keeping with the emissions of CO₂ (and other GHGs) associated with the use of those fuels. This raises production costs and tends to discourage investment. According to the NEMS–RFF model (see Figure 5), the adverse impact on aggregate investment is particularly strong in the first 10 years following implementation. As expected, the impacts are less severe the greater the availability of offsets and the less stringent the cap.

However, cap and trade’s impact on investment is not uniform across all firms. The policy improves the competitive position of low-carbon fuels and of products (such as hybrid cars) that require less use of such fuels. As a result, it can promote greater investments toward

the development of alternative fuels and increased investments by firms producing low-carbon products.

Figure 6. Consumption Impacts as a Function of Cap Stringency and Offset Availability (Percentage Changes from Reference Case)



According to the NEMS–RFF model, cap and trade has a positive impact on consumption, as indicated by Figure 6. This result runs contrary to the results from most other climate policy models. For example, the Goulder E3 model predicts that a cap-and-trade program very similar to the Central case would cause aggregate consumption to decline by 0.2–0.4 percent in 2020 and by 0.6–0.8 percent in 2030, relative to business as usual. The Intertemporal General Equilibrium Model used by the U.S. Environmental Protection Agency (EPA) estimates that the Waxman–Markey bill would lead to reductions in aggregate consumption of 0.1 percent and 0.3 percent in 2020 and 2030, respectively. Similarly, the Applied Dynamic Analysis of the Global Economy model used by EPA in the same analysis estimates reductions of 0.11 percent and 0.31 percent in 2020 and 2030, respectively.

The different results for the NEMS–RFF model appear to stem from the model’s unusual specification of household consumption and saving: when investment falls, households reduce their savings to accommodate the fall in investment. The decline is so large that considerable income is freed up for consumption. In most other models, the fraction of household income that households wish to devote to consumption and saving tends to be much more stable. In these

other models, if a policy exerts downward pressure on investment, household saving does not automatically fall to accommodate the reduction. Because saving does not drop so far, consumption falls.

Table 1 indicates cap and trade's impacts on GDP and its components for selected years. In the NEMS–RFF simulations, cap and trade causes exports to decline, reflecting the increased costs of producing goods for export and the associated export prices. At the same time, the model predicts that cap and trade will boost imports. Although this is possible, the model does not consider exchange rate issues (the balance between the demand for and supply of dollars) or impose a balance of payments. Equilibrium in the foreign exchange market requires that a current account deficit (such as the one predicted by the NEMS–RFF model) be accompanied by a surplus on the capital account (that is, net lending to the United States by foreigners). The inattention to balance of payments considerations means that the model biases upward the impact on imports because a worsening of the balance of trade tends to imply a reduction in the demand for dollars and a fall in the dollar, which implies an increase in the price of imports. In addition, because the model does not consider the capital account, it does not capture the costs to the U.S. economy of the interest payments it must make to foreign lenders.

Table 1. Impacts on GDP and Its Components as a Function of Offset Availability and Stringency of Cap

Case	Year			
	2015	2020	2025	2030
Reference case (billions of 2000\$)				
Real GDP	13,450	15,399	17,552	19,871
Consumption	9,497	10,814	12,357	14,062
Investment	2,191	2,591	3,066	3,588
Government spending	2,109	2,229	2,349	2,473
Exports	2,047	2,862	3,760	4,866
Imports	2,331	2,939	3,708	4,715
Central C&T (% change)				
Real GDP	-0.29	-0.34	-0.57	-0.82
Consumption	0.18	0.36	0.46	0.61
Investment	-1.42	-1.15	-1.07	0.05
Government spending	-0.12	0.05	0.24	0.55
Exports	-0.79	-1.72	-3.01	-4.51
Imports	0.52	1.11	1.68	3.05
Greater Offset Availability (% change)				
Real GDP	-0.21	-0.29	-0.41	-0.52
Consumption	0.12	0.23	0.34	0.50
Investment	-0.97	-0.84	-0.77	0.08
Government spending	-0.08	0.03	0.17	0.41
Exports	-0.58	-1.26	-2.13	-3.19
Imports	0.41	0.88	1.21	2.14
No Offsets (% change)				
Real GDP	-0.48	-0.46	-1.07	-1.32
Consumption	0.33	0.70	0.72	1.13
Investment	-2.48	-1.74	-1.77	0.59
Government spending	-0.19	0.14	0.40	0.99
Exports	-1.30	-2.83	-5.05	-7.39
Imports	0.89	1.80	3.26	5.86
Less Stringent Cap (% change)				
Real GDP	-0.17	-0.21	-0.33	-0.40
Consumption	0.13	0.27	0.41	0.65
Investment	-0.89	-0.82	-0.96	-0.42
Government spending	-0.07	0.02	0.14	0.36
Exports	-0.52	-1.10	-1.93	-2.88
Imports	0.34	0.71	1.04	1.94

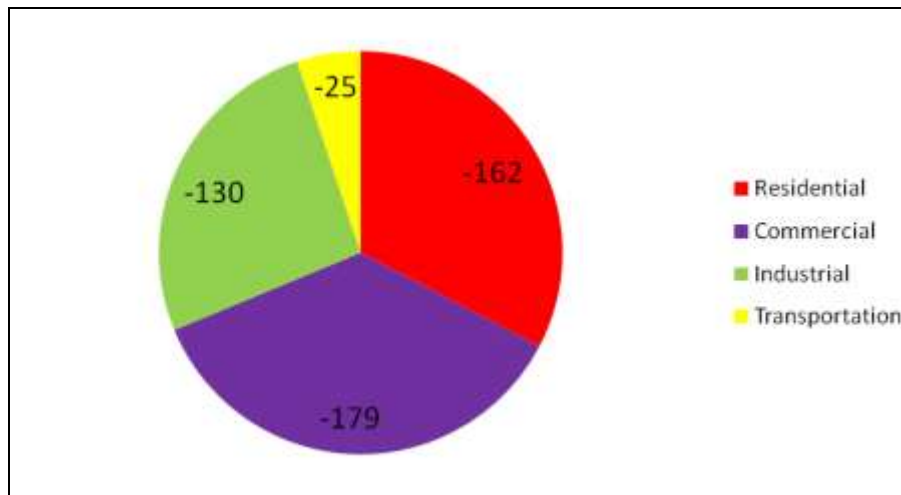
Note: Reference case figures are in billions of 2000\$; other figures are as a percentage change from Reference case.

D. Emissions Reductions by Sector

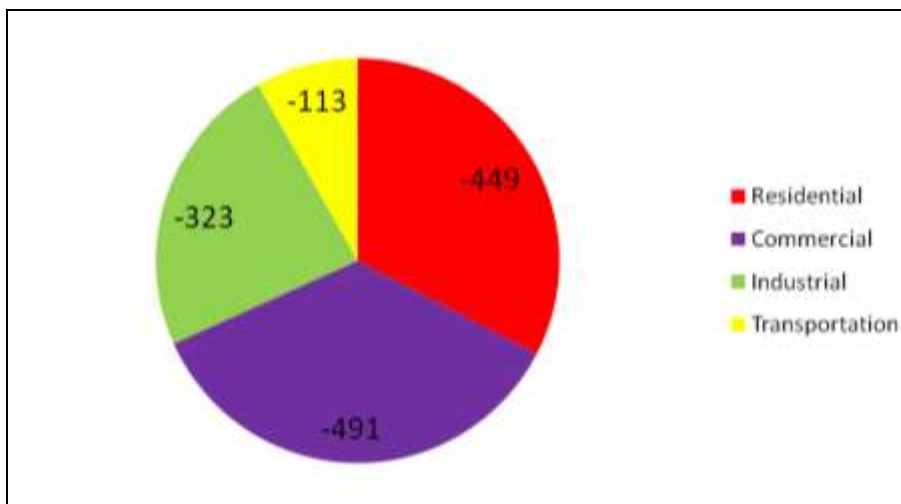
Figure 7 indicates how different sectors of the economy contribute to emissions reductions in the years 2020 and 2030. The reductions for the residential, commercial, industrial, and transportation sectors include the emissions reductions associated with reduced demands for electricity by these sectors.

Figure 7. Changes in CO₂ Emissions by Sector in 2020 (Top) and 2030 (Bottom), in Millions of Tons

2020



2030



Note: Negative numbers indicate emissions reductions.

According to the NEMS–RFF model, the transportation sector contributes only a small share of the emissions reductions. The carbon emissions price is a much smaller percentage of the total delivered price of gasoline or diesel than of the delivered price of coal or natural gas. As a result, cap and trade will raise the effective price of these motor fuels (the price inclusive of the associated cost of emissions allowances) by far less than it raises the price of the coal for electric power generators or of natural gas for various industrial, commercial, and residential users, as indicated in Table 2. Hence, the emissions reductions from the transportation sector are considerably smaller than those from the electricity sector.

The small relative contribution of the transportation sector to the overall reductions is in keeping with minimizing the total cost of achieving given emissions reduction targets. If transportation were to contribute a larger share, the costs per avoided ton (at the margin) would be higher in transportation than in other sectors.

However, transportation’s inclusion within the cap-and-trade system—even if its contribution to emissions reductions is small—helps minimize costs. Because a cap-and-trade program is likely to generate relatively little reduction in emissions from transportation, some analysts argue that transportation should not be covered under cap and trade. However, as indicated in section 4 below, including transportation within the cap-and-trade system is likely to reduce the costs of achieving any given target for nationwide emissions reductions. This is because greater breadth enables cap and trade to exploit more of the low-cost opportunities for emissions reductions.

Table 2. Impacts of Cap and Trade on Fuel Prices

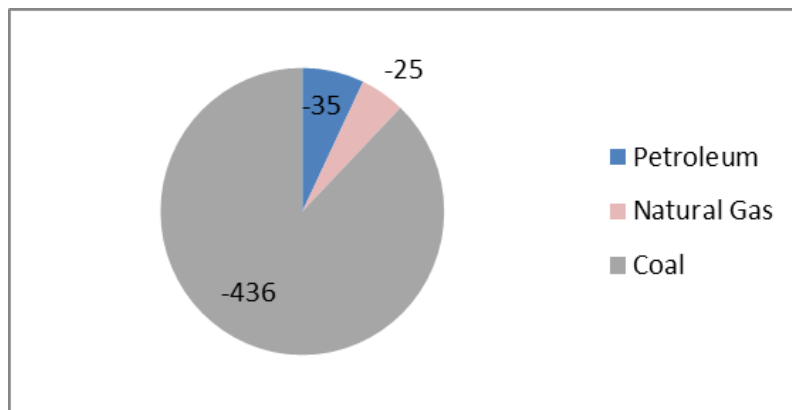
	Percentage change from Reference case	
	2020	2030
Delivered price of natural gas		
Residential	12.4	21.1
Commercial	13.8	22.9
Industrial	18.8	30.8
Delivered price of coal	148.8	290.5
Gasoline price	6.4	14.1

E. Emissions Reductions by Fuel

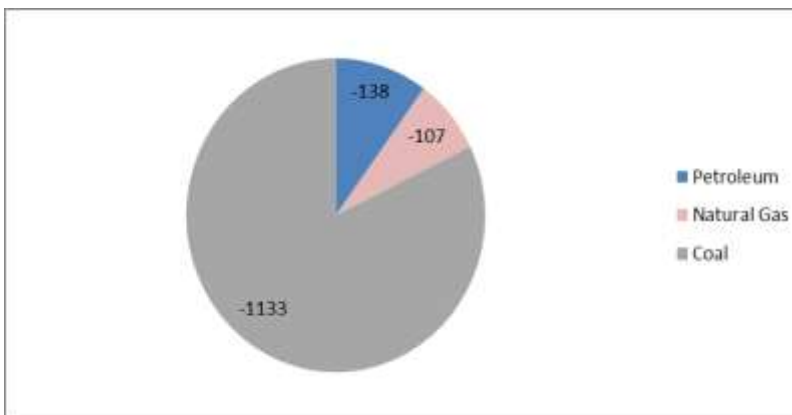
In keeping with the fact that the effective coal price rises by far more than the effective prices of refined petroleum fuels or delivered natural gas, most of the reductions in CO₂ emissions come from coal, as indicated by Figure 8.

Figure 8. Changes in CO₂ Emissions by Fuel Type in 2020 (Top) and 2030 (Bottom), in Millions of Tons

2020



2030



Note: Negative numbers indicate emissions reductions.

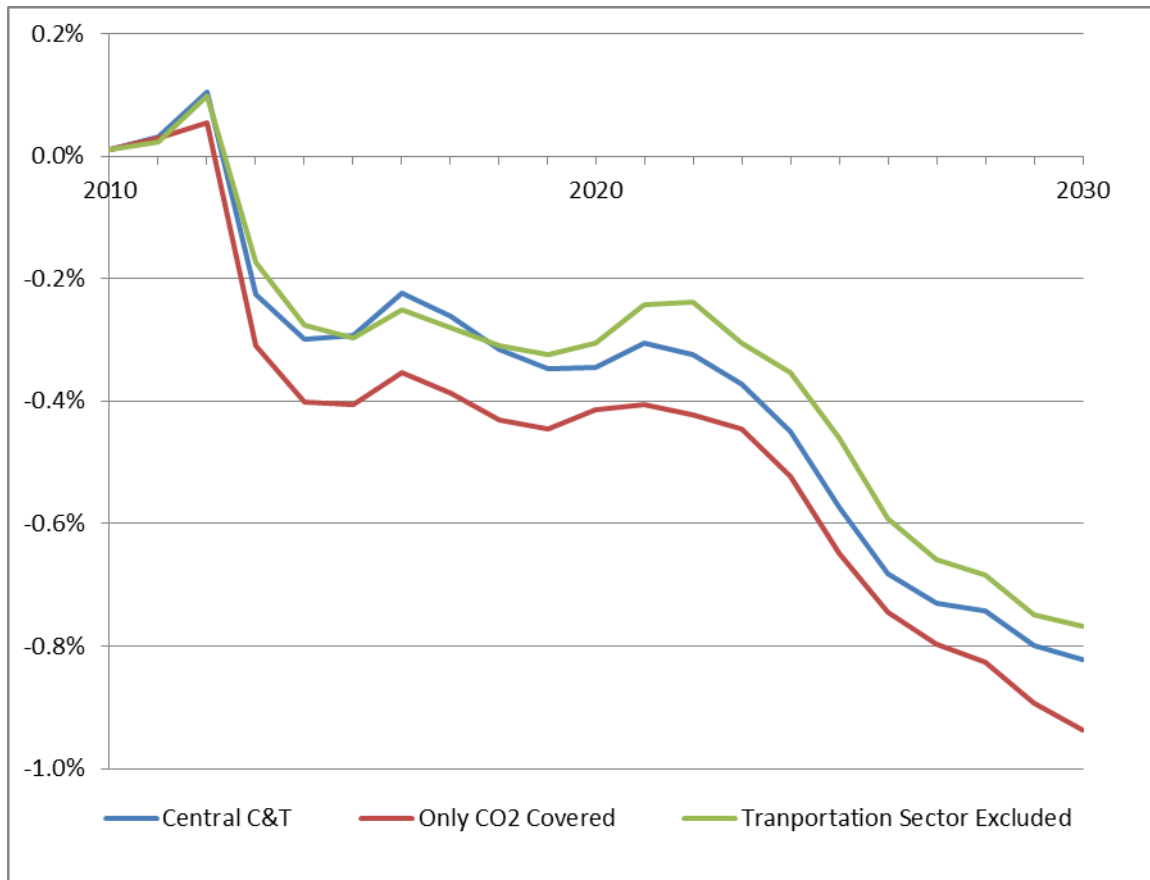
4. Other Design Issues

A. The Significance of Scope

Beyond determining the stringency of the cap and the extent to which offsets might be allowed, policymakers need to make other important choices as to policy design. Two important additional choices are the range of GHGs the system should embrace and the range of economic sectors to be covered by the system.

To explore this issue, further simulations with the NEMS–RFF model were performed. Figure 9 shows how GDP costs depend on these design features.

Figure 9. GDP Impacts as a Function of Policy Scope (Percentage Changes from Reference Case)



Narrowing the scope of cap and trade by excluding non-CO₂ GHGs implies larger GDP costs of achieving a given overall reduction target. However, the additional GDP costs do not appear to be exceptionally large. The other gases do not contribute a particularly large share to U.S. emissions; hence, requiring all reductions to come from CO₂ does not greatly add to costs.

In the Reference case, non-CO₂ GHGs make up only 20 percent of total CO₂e GHGs in 2020 and 22 percent in 2030.

Likewise, as noted above, theory predicts that the GDP costs of achieving a given aggregate reduction under cap and trade are greater when the cap-and-trade program excludes transportation. However, the NEMS–RFF simulation gives the opposite result, although no clear explanation is offered. (On the other hand, as indicated below, calculations based on output from the NEMS–RFF model indicate that, in keeping with theory, the *welfare cost* per ton of reduced emissions is greater when transportation is excluded.)

B. Intertemporal Flexibility

GDP Impacts. The Central case simulation incorporates intertemporal flexibility: compliance entities can bank some or all of the current allowances and use them in a future period. In considering whether to bank any allowances, cost-minimizing firms will consider current and future abatement costs and allowance prices. If a firm expects that future abatement costs and allowance prices are likely to be quite high relative to the current costs and prices, it will have an incentive to bank some allowances. In doing so, it reserves current and relatively inexpensive allowances for use in the future, thus avoiding some high abatement costs and high-cost allowance purchases. Provisions for banking cause firms to substitute relatively inexpensive current-period abatement for more costly future abatement without changing the total abatement over the relevant time interval. As a result, it lowers society’s overall costs of achieving a given cumulative emissions reduction.

In Figure 10, I compare the GDP costs of cap and trade in the Central case⁶ and in an alternative case with no banking provisions. Contrary to the theoretical predictions, the GDP costs are *smaller* in the absence of banking provisions. Allowing for banking (as in the Central C&T case) leads to greater short-term reductions than would otherwise be the case (see Figure 11). In the absence of banking, the present values of allowance prices are higher in the longer term than in the nearer term. As a result, when banking is permitted, firms can lower their compliance costs by banking allowances and reducing the needed purchases of allowances in the longer term. Under banking, firms avoid undergoing especially high (in present value) marginal costs of abatement. Thus, allowance banking can be expected to reduce the GDP costs, in

⁶ In the Central case, aggregate bank balances must go to zero by 2030, meaning that, by 2030, each compliance entity must have used up all previously banked allowances.

keeping with lower abatement costs to firms. Most economic simulation models arrive at this result; the NEMS-RFF model's results are an exception.

Figure 10. GDP Impacts in the Presence and Absence of Allowance Banking Provisions (Percentage Change from Reference Case)

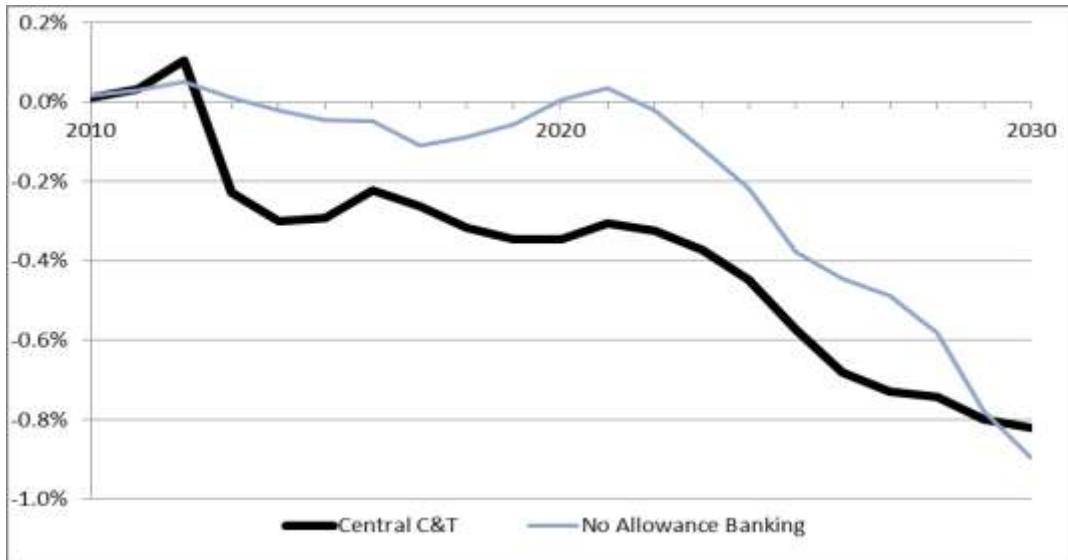
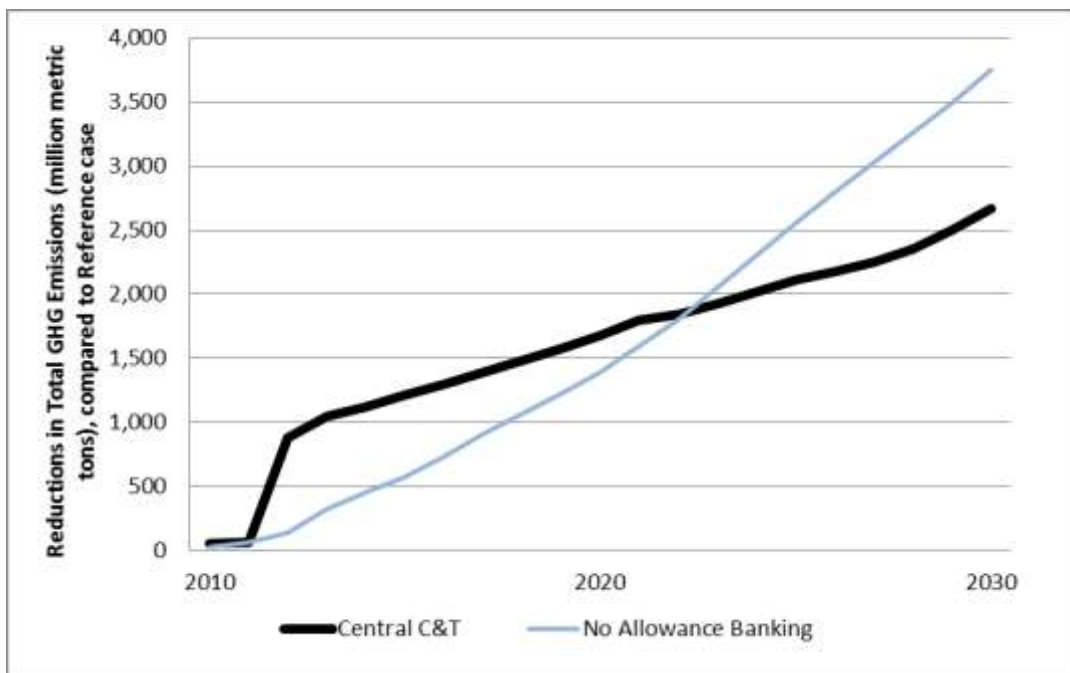


Figure 11. Emissions Reductions in the Presence and Absence of Allowance Banking Provisions



C. International Emissions Leakage

To the extent that cap and trade raises costs to domestic producers relative to foreign competitors, domestic firms can lose market share relative to foreign firms. In addition, *emissions leakage* can occur: the reduced emissions associated with the contraction of domestic output can be offset to a degree by increased production and emissions abroad. The NEMS model does not calculate the impacts of cap and trade on foreign emissions. Thus, it cannot measure the extent of emissions leakage.

A cap-and-trade program can include elements to reduce leakage. For example, output-based allowance updating, which gives firms incentives to maintain output despite the constraint on emissions, could be applied to firms in energy-intensive, trade-exposed industries. Another option is to introduce border taxes that reduce policy-induced disparities between domestic and foreign goods.

5. Efficiency Costs per Ton across Policy Alternatives

One useful measure of economic cost is the *efficiency cost*—sometimes referred to as *excess burden* or *deadweight loss*. In principle, the efficiency cost accounts for the full resource cost of a given policy.⁷ The efficiency cost in a given year from a given policy to reduce emissions can be calculated as $0.5 \times -\Delta E \times p_E$, where $-\Delta E$ is the reduction in emissions and p_E is the price of allowances. The cost over the interval 2010–2030 is the present value of the annual efficiency costs. A useful measure for comparing policies is this present value divided by the cumulative emissions reductions achieved; this is the overall efficiency cost per cumulative tons reduced. Table 3 compares the alternative cap-and-trade policies using this measure.

⁷ The efficiency cost measure accounts for resource costs, such as losses of leisure time, that are not reflected in other cost measures, such as lost GDP.

Table 3. Efficiency Costs per Ton for Alternative Cap-and-Trade Policies

Alternative policies	Efficiency cost ^a
Less Stringent Cap	6.56
Greater Offset Availability	7.46
No Allowance Banking	8.86
Central C&T	10.24
Transportation Sector Not Covered	11.01
Only CO ₂ Covered	12.25
No Offsets	17.82

^aCost in \$2007 per ton of CO₂ reduced

In most cases, the rankings in Table 3 correspond to the rankings in terms of GDP costs. Greater availability of offsets lowers the efficiency costs, as does a less stringent cap. Importantly, the figures in Table 3 do not account for the environmental benefits associated with reduced emissions. Thus, although a less stringent cap entails lower costs per ton, it also yields smaller environmental benefits. A narrower cap-and-trade system implies higher costs per ton because it restricts opportunities for low-cost reductions. Thus the costs per ton are higher when non-CO₂ GHGs are excluded or when the transportation sector is not covered.

An anomalous result from the NEMS–RFF model is that the estimated costs per ton are lower in the absence of allowance banking. In theory, banking should lower costs because it enables producers to alter the timing of emissions reductions so as to achieve the reductions when they are least costly (in present value). Yet the NEMS–RFF model suggests that precluding banking leads to lower costs.

6. Recycling of Policy-Generated Revenues

The NEMS–RFF model’s treatment of cap and trade implicitly involves the auctioning of allowances and the return of auction revenues to households as lump-sum transfers. An alternative is to return auction revenues through cuts in the marginal rates of existing taxes, such as income or sales taxes. Previous theoretical and empirical work indicates that this can substantially reduce the costs of cap and trade to the overall economy.

The NEMS–RFF model is not well equipped to examine this issue. To consider this issue, I focus on results from simulations using the Goulder E3 model. With this model, I consider cap-

and-trade policies in which the time profile of the cap follows the Waxman-Markey bill, as with the simulations considered previously in this paper.⁸ The simulations include cases in which emissions allowances are auctioned. In one simulation, the net⁹ auction revenue is recycled to households as lump-sum rebates (as in the NEMS–RFF model). In another, this revenue is used to finance reductions in the marginal rate of individual income taxes. The results are shown in Table 4.

Table 4. Implications of Alternative Revenue-Recycling Methods for GDP Costs

Policy design	Percentage reduction in GDP ^a		
	2020	2030	2009–2030 ^b
100% Auctioning			
Recycling via lump-sum transfers	0.77	2.70	0.81
Recycling via marginal income tax rate cuts	0.35	2.21	0.47
100% Free allocation	0.75	2.67	0.79

^a Percentage change in the present value of GDP. ^b Percentage change over this interval.

Source: Goulder et al. 2009.

In these simulations, the method of revenue recycling makes a substantial difference to GDP costs. The GDP costs are about 40 percent lower when revenues are used to finance income tax rate cuts. Income taxes lead to reduced production and incomes by reducing work incentives as well as incentives to save and invest. In economics lingo, these taxes are *distortionary* in that they cause the overall economy to shrink (even after recycling the tax revenue or devoting the revenue toward public spending). The magnitude of the distortion increases with the tax rate. The *marginal excess burden* from these taxes has been estimated to fall in the range of \$0.20 to \$1.00; this means that, for every extra dollar collected from these taxes, the loss of value created by the private sector (before returning the tax revenue) is between \$1.20 and \$2.00.¹⁰ Using auction revenue to finance cuts in the marginal rates of these existing taxes enables the state to

⁸ The results shown are from a cap-and-trade policy with no provision for offsets.

⁹ I refer to *net* revenue because the relevant value is gross auction revenue minus the change in tax revenue associated with changes in the tax base. To the extent that a federal cap-and-trade program reduces (increases) national income, the income tax base will fall (rise), and revenues from other taxes will fall (rise) as well.

¹⁰ See, for example, Auerbach and Hines (2002), Browning (1987), Ballard et al. (1985), and Jorgenson and Yun (1991).

avoid this excess burden. In effect, by using auction revenue to finance tax cuts, the United States would rely on a nondistortionary source of revenue—the proceeds from an allowance auction—as a substitute for the distortionary income tax. One can think of it as akin to green tax reform.

Policymakers also have the option of awarding allowances free to compliance entities, rather than auctioning the allowances. In this case, the policy yields no revenue. Thus, it offers no opportunity to finance cuts in income tax rates. Table 4 also displays results from a simulation involving free allocation of allowances. In this case, the GDP impacts are very similar to the case where net proceeds from an allowance auction are recycled as lump-sum rebates, in keeping with the fact that the policy leads to no marginal rate cuts.

7. The Carbon Tax Alternative

Many analysts favor a carbon tax as an alternative to cap and trade. Like cap and trade, a carbon tax establishes a price on carbon emissions, thereby encouraging conversions to lower-carbon fuels in production as well as stimulating reductions in demands for carbon-intensive products. Under such a carbon tax, it pays for a firm to reduce emissions if its cost of abatement is less than the avoided tax from such abatement. Similarly, under cap and trade, it pays for a firm to reduce emissions if its cost of abatement is less than the allowance price.

Although the two policies have these similar incentive effects, they also differ in some significant ways, perhaps most crucially in the nature of uncertainty and the potential for price volatility.

A. Locus of Uncertainty

A main difference between a carbon tax and cap and trade is that a carbon tax sets the price of emissions (the tax rate), whereas the extent of emissions (or emissions reductions) is determined by the market response. Thus, the emissions price is known with certainty, whereas the quantity of emissions associated with the policy is not known in advance. Under cap and trade, the locus of uncertainty is different. In this case, the regulator knows at the outset the emissions quantities (the quantities of allowances circulated), whereas the price of emissions (the allowance price) is determined by the market and is not known in advance.

For many environmental groups, the fact that a carbon tax does not guarantee that emissions will be kept within a given limit is a crucial liability. These groups indicate that uncertainty about emissions quantities (under a carbon tax) raises the possibility that emissions will significantly exceed desired levels. At the same time, some business groups abhor the fact that cap and trade leaves prices uncertain. They emphasize that uncertainty about emissions

prices (under cap and trade) constrains the business community's ability to respond to climate policy: changing the input mix (for example, engaging in fuel substitution) and investing in research toward new technologies is more risky when future allowance prices are uncertain.

Which of these two risks—high environmental damages or high abatement costs—is more important? This is an empirical matter. On this issue, some analysts refer to the significant contribution of Weitzman (1974), who compared the expected efficiency losses from inaccurate price-based regulation (as with carbon taxes) with those from quantity-based regulation (as with cap and trade) in the presence of uncertainty about costs and damages. His analysis indicates that, when the marginal damage function is relatively steep (as a function of emissions), then a quantity-based instrument (like cap and trade) is superior to a price-based instrument (like a carbon tax) in the sense that it yields a larger expected value of efficiency gains. In contrast, when the marginal abatement cost function is relatively steep (as a function of emissions reductions), a price-based instrument yields larger expected efficiency gains.

Because the NEMS–RFF model does not consider uncertainty, it cannot directly address this particular contrast between cap and trade and a carbon tax. Any given cap-and-trade policy in the NEMS–RFF model will result in a particular time profile of allowance prices and a particular set of economic outcomes. If one used this model to simulate a GHG emissions tax policy instead of cap and trade—and, in particular, if one imposed a time profile of GHG emissions taxes equal to the previously mentioned time profile of allowance prices, then the economic outcome would be the same as under the corresponding cap-and-trade policy.

B. Price Volatility

Emissions price volatility is not a problem for a carbon tax. Under a carbon tax policy, the emissions price is the tax rate, and presumably the rates change smoothly through time, if they change at all. But this is a major issue for a cap-and-trade system, where the emissions price is the allowance price. Under cap and trade, the supply of allowances is perfectly inelastic—fixed in any given period of time. When the supply is perfectly inelastic, shifts in demand can cause significant price changes.

Some existing cap-and-trade systems have, in fact, displayed considerable allowance price volatility. The energy supply crisis in California in summer 2000 gave power companies incentives to bring online some older power generators in the Los Angeles region. This led to a significant increase in the demand for nitrogen oxide (NO_x) emissions allowances under the Regional Clean Air Incentives Market program because allowances were needed to validate the emissions produced by these generators. As a consequence, NO_x allowance prices rose from about \$400 per ton to more than \$20,000 per ton between May and August 2000.

One way to reduce potential price volatility is to allow for intertemporal banking and borrowing of allowances, as described above. Intertemporal flexibility makes the current supply of allowances more elastic and thus can dampen price volatility. With this in mind, several senators have proposed the creation of a carbon market efficiency board whose purpose would be to alleviate price volatility of a federal cap-and-trade system by expanding, as necessary, provisions for intertemporal borrowing and banking. Metcalf (2007) points out, however, that introducing such a system would raise uncertainties as to when and how the board would act.

Another way to address volatility is to add a *safety valve* component to a cap-and-trade system (Pizer 2002; Jacoby and Ellerman 2004; Burtraw and Palmer 2006). The safety valve establishes a price ceiling for allowances: if the allowance price reaches the ceiling price, the safety valve is triggered—that is, the regulator is authorized to sell whatever additional allowances must be introduced into the market to prevent allowance prices from rising further. One of the most significant climate policy bills introduced in the 110th Congress—S. 1766, sponsored by Jeff Bingaman (D-NM) and Arlen Specter (R-PA)—contained a safety valve.¹¹

It is also possible to enforce a price floor by authorizing the regulator to purchase (withdraw from the market) allowances once the allowance price falls to the preestablished floor price.

The safety valve reduces price uncertainty by establishing a ceiling price; however, like the carbon tax, it introduces emissions uncertainty. In effect, a cap-and-trade system becomes a carbon tax when the safety valve is triggered. Some proponents of a carbon tax tend to see little reason to have a “hybrid” policy of cap and trade with a safety valve. On the other hand, many analysts like the hybrid, believing that it combines nicely the attractions of cap and trade (in particular, establishing a clear emissions reduction target when the trigger price is not activated) with that of a ceiling price.

8. Key Results and Implications for Policy

This paper focuses on the impacts of a cap-and-trade policy that requires GHG reductions corresponding to those required by the Waxman-Markey bill. I find that the design of the cap-

¹¹ Senate Bill 2191, sponsored by Joseph Lieberman (I-CT) and John Warner (R-VA) and the Waxman–Markey bill also contain provisions to dampen potential fluctuations in allowance prices. These bills include a “carbon allowance reserve,” which would enable the government to introduce up to a fixed amount of reserve allowances at certain trigger prices.

and-trade program is important to policy costs. Efficiency costs are lower when the cap-and-trade program has broader sector coverage and when it extends to a broader range of GHGs.

Especially significant to policy costs are the assumptions or constraints relating to offsets. With annual limits of \$0.5 billion each for domestic and international offsets, cap and trade (at a level of stringency corresponding to that in the Waxman-Markey bill) implies efficiency costs of about \$10 per ton of emissions reductions on average over the interval 2010–2030. Raising the limits to \$1 billion each reduces the efficiency costs to about \$7.50 per ton. In the absence of offsets, the efficiency costs rise to about \$18 per ton. It is important to recognize the great uncertainty about the extent to which claimed offsets would correspond to true emissions reductions. Thus, although generous provision for offsets might seem to affect policy costs significantly, it is less clear whether this leads to lower costs per ton of *actual* emissions reductions.

This analysis indicates that cap and trade, by itself, does not lead to very large reductions in oil consumption. This is because the impact on gasoline and other petroleum-based fuels is small relative to the impact on coal.

The analysis also shows that *GDP costs depend substantially on how any policy-generated revenues are recycled*. Policy costs are approximately 40 percent smaller when emissions allowances are auctioned and the revenues from the auction are used to finance reductions in marginal income tax rates, compared with the case where auction revenues are returned in a lump-sum fashion (e.g., as rebate checks) or where allowances are given out free without a possibility of revenue recycling.

The above simulation results and associated discussion lead to the following policy recommendations:

- ***Work toward Broad Coverage.***¹² Breadth helps reduce costs per ton of avoided emissions. To the extent practicable (in particular, when monitoring costs are not prohibitive), include other GHGs as well as CO₂ in the cap-and-trade system. Incorporate similarly broad coverage across economic sectors. Include transportation as a covered sector, even if impacts on oil consumption are small. If, for other reasons (other market

¹² Broader sector coverage implies lower costs in nearly all economic analyses. However, as noted above, the NEMS model produces the surprising result that narrowing the scope by excluding transportation from cap and trade would lower the costs of achieving a given reduction target. No clear explanation for this anomalous result is available.

failures), further reductions in carbon (oil) demands from transportation are called for, then this should be accomplished via an additional, complementary policy.

- ***Replace Offset Provisions with Price Incentives for Similar GHG-Reducing Actions.*** Regarding the additionality problem associated with offsets, several studies suggest that many, if not most, of the emissions reductions from offsets under the Kyoto Protocol's Clean Development Mechanism are not additional—that is, the changes in emissions would have occurred even in the absence of the offset provisions. Thus, the apparent cost savings from offsets are not real savings: costs per actual reduction in emissions may be higher in the presence of offsets than in their absence. A more cost-effective approach might be to replace offset provisions with alternative policies to complement cap and trade, including subsidies for carbon sequestration (whether in the form of forestry-related sequestration or carbon capture and storage) and for renewable energy development. By including these complementary policies, the costs of achieving *true* emissions-reduction targets can be reduced.
- ***Emphasize Auctioning (Rather Than Free Provision) of Emissions Allowances, and Use Auction Revenue to Displace Ordinary (Distortionary) Taxes.*** Auctioning is a particularly transparent way to put allowances into circulation. Using auction revenues to replace ordinary tax revenue can lower policy costs substantially.
- ***Include Provisions to Contain International Emissions Leakage:*** Emissions leakage can be a serious problem. Output-based allocation to trade-exposed, carbon-intensive industries can help these industries maintain market share with foreign competitors not facing climate policies and associated cost increases. Border adjustments are an alternative way to address leakage.

One final policy option that deserves consideration—though further research is needed to determine whether it would be beneficial overall—is to append a price ceiling (or safety valve) to a cap-and-trade program to reduce the potential for allowance price volatility. Such volatility is a possible drawback of cap and trade relative to a carbon tax because volatility can lead to macroeconomic disruptions and associated economic costs. A price ceiling could address this issue.¹³ On the other hand, flexibility of allowance prices is a potential virtue to the extent that allowance prices might move countercyclically. In a depressed economy, for example, lowered demand is likely to produce lower allowance prices; this could reduce the economic impact of

¹³ A price floor also can be an attractive option as it can help provide continued incentives to potential inventors and suppliers of alternative fuels or of products involving lower carbon input.

cap and trade relative to the case with fixed allowance prices (as under a carbon tax). The issue deserves further attention.

References

- Auerbach, A.J., and J.R. Hines, Jr. 2002. Taxation and Economic Efficiency. In *Handbook of Public Economics*, vol. 1, edited by A.J. Auerbach and M.L. Feldstein. Amsterdam: Elsevier.
- Ballard, C.L., J. Shoven, and J. Whalley. 1985. General Equilibrium Computations of the Marginal Welfare Costs of Taxes in the United States. *American Economic Review* 75: 128–138.
- Browning, E.K. 1987. On the Marginal Welfare Cost of Taxation. *American Economic Review* 77 (1): 11–23.
- Burtraw, D., and K. Palmer. 2006. *Dynamic Adjustment to Incentive-Based Environmental Policy to Improve Efficiency and Performance*. Washington, DC: Resources for the Future.
- Congressional Budget Office. 2009. *The Use of Offsets to Reduce Greenhouse Gases*. Economic and Budget Issue Brief, August 3. <http://www.cbo.gov/ftpdocs/104xx/doc10497/08-03-Offsets.pdf> (accessed January 19, 2011).
- Goulder, Lawrence H., Marc A.C. Hafstead, and Michael Dworsky. 2009. Impacts of Alternative Emissions Allowance Allocation Methods under a Federal Cap-and-Trade Program. Working paper, July. Stanford, CA: Stanford University.
- Jacoby, H.D., and A.D. Ellerman. 2004. The Safety Valve and Climate Policy. *Energy Policy* 32(4): 481–491.
- Jorgenson, D.W., and K.-Y. Yun. 1991. The Excess Burden of U.S. Taxation. *Journal of Accounting, Auditing, and Finance* 6(4): 487–509.
- Metcalf, Gilbert. E. 2007. A Proposal for a U.S. Carbon Tax Swap: An Equitable Tax Reform To Address Global Climate Change. Discussion paper 2007-12, The Hamilton Project. Washington, DC: The Brookings Institution.
- Pizer, William A. 2002. Combining Price and Quantity Controls to Mitigate Global Climate Change. *Journal of Public Economics* 85: 409–434.
- Wara, Michael, and David G. Victor. 2008. A Realistic Policy on International Carbon Offsets. Program on Energy and Sustainable Development working paper no. 74, April. Stanford, CA: Stanford University.
- Weitzman, Martin L. 1974. Prices vs. Quantities. *Review of Economic Studies* 41: 477–491.