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# Impacts of alternative emissions allowance allocation methods under a federal cap-and-trade program

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ABSTRACT

This paper examines the implications of alternative allowance allocation designs for industry profits and GDP under a federal cap-and-trade program to reduce greenhouse gas emissions. We employ a general equilibrium model of the U.S. economy with a unique treatment of capital dynamics that permits close attention to profit impacts.

Effects on profits depend critically on the relative reliance on auctioning or free allocation of allowances. Freely allocating fewer than 15% of the emissions allowances generally suffices to prevent profit losses in the most vulnerable U.S. industries. Freely allocating all of the allowances substantially overcompensates these industries. When emissions allowances are auctioned and the proceeds employed to finance cuts in income tax rates, GDP costs are about 33% lower than when all allowances are freely allocated. Our results are robust to policies differing in stringency, the availability of offsets, and the opportunities for intertermporal trading of allowances.

## 1. Introduction

Cap and trade has emerged as the centerpiece of discussions of potential federal-level climate-change policies. Within discussions of alternative cap-and-trade programs, there has been an intense focus on the issue of how emissions allowances might be allocated and how the revenues from an allowance auction (if any) might be used. What fraction of the allowances should be auctioned out, as opposed to given out free? How much free allocation would be sufficient to preserve profits in various industries? What are the economy-wide implications of alternative uses of whatever auction revenues are collected?

Despite considerable and sometimes contentious debate on these issues, there have been very few quantitative analyses of industry profit impacts and associated GDP consequences under a range of allocation methods.[1] One reason is that many of the leading models employed to investigate cap-and-trade policy, while offering very important and policy-relevant insights, are not well suited to examining potential impacts on profits. Some of the models[2] assume that physical capital is

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[1] Burtraw et al. [1] investigated the implications of alternative allocation methods for profits and asset values in the HAIKU model, which focuses on the electricity sector. Bovenberg and Goulder [2] and Smith et al. [3] considered alternative allocations using general equilibrium models with a relatively primitive treatment of cap and trade, as discussed below. See Ramseur [4] for a review of existing studies of the impacts of alternative allowance allocation designs.

[2] The IGEM model developed by Dale Jorgenson and his collaborators assumes perfectly mobile capital. Details on this model are contained in Goettle et al. [5].

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perfectly mobile across the economy, which means that capital can instantly flow out of one sector and into another in response to a change in economic conditions. This precludes an assessment of the differential profit impacts across industries, since it eliminates the possibility of stranded assets and instead implies that capital in all sectors instantly regains the same productivity following a policy intervention.

Other models adopt a "putty-clay" approach to capital dynamics, according to which capital is completely immobile once it is installed.[3] This approach may exaggerate the problem of stranded assets, since it does not allow for any removal or sale of previously installed capital; capital stocks can only decline through physical depreciation. Thus, the coal mining industry, for example, would be prevented from significantly reducing its equipment as part of its effort to respond to reduced coal demand resulting from a cap-and-trade program.

The present study offers results from a numerical general equilibrium model of the U.S. economy that is uniquely well-suited to assessing the profit impacts across various industries under possible cap-and-trade program designs. In contrast with other models,[4] it derives both investment and disinvestment behavior from optimizing decisions at the industry level. Forward-looking managers in each industry make decisions that account for the adjustment costs associated with the installation or removal of productive capital.

This approach permits a close examination of how profits are affected in various industries under a range of allocation approaches. As discussed below, the impacts differ dramatically depending on the extent to which auctioning or free allocation is employed. When a firm must purchase all of its allowances (as is the case when all allowances are auctioned) the potential policy-generated rents (or, equivalently, the value of emissions allowances) are transferred from the firm to the government. In contrast, when a firm receives allowances free, it retains these rents. This makes an enormous difference. Indeed, it generally determines whether cap and trade causes a reduction (the 100% auction case) or an increase (the 100% free allocation case) in the firm's profit.

This paper applies the model to assess how policy impacts differ across various types of emissions allowance allocation. We consider policies that vary in terms of both the reliance on free versus auctioned allowances and the use of revenues from allowance auctioning (if applicable). These alternatives are evaluated under programs that differ in terms of policy stringency (the total number of allowances put in circulation), the points of regulation, the availability of offset programs, and the possibility of intertemporal banking or borrowing of allowances. These are central considerations in current policy discussions, including the American Clean Energy and Security (ACES) Act passed in June 2009 by the U.S. House of Representatives.

We find that freely allocating a relatively small fraction of the emissions allowances generally suffices to prevent profit losses among the eight industries that, without free allowances or other compensation, would suffer the largest relative losses of profit. Under a wide range of cap-and-trade designs, freely allocating less than 15% of the total allowances prevents profit losses to these eight most vulnerable industries. Freely allocating 100% of the allowances substantially overcompensates these industries, in many cases leading to profit increases of over 100%.

These results indicate that profit-preservation is consistent with auctioning the lion's share of allowances. One important potential use of auction revenues is to finance reductions in the marginal tax rates of ordinary, distortionary taxes such as income, sales, and payroll taxes. This is important for the GDP and efficiency costs of cap and trade. When just enough free allocation is offered to compensate (but not overly compensate) the most vulnerable industries, considerable auction revenue is generated, yielding significant opportunities to avoid distortionary taxation. Our numerical simulations indicate that when these revenues are used to finance cuts in marginal rates of individual income taxes, the resulting GDP costs are about one third lower than in the case where all allowances are freely allocated and no auction revenue is generated. In contrast, the cost-advantages of auctioning disappear when the auction proceeds are returned to the economy in lump-sum fashion (for example, as rebate checks to households).

The rest of this paper is organized as follows: Section 2 offers a graphical analysis to convey how a firm's profits under a cap-and-trade program are influenced by the way allowances are allocated, the emissions-reduction opportunities of the firm, the costs of adjusting physical capital, and demand for the firm's product. Section 3 describes the numerical model used for the quantitative assessments. Section 4 discusses the model's data and parameters. Section 5 describes and interprets the model's results. Section 6 concludes.

## 2. Allowance allocation, profits, and economy-wide cost: a graphical illustration

The nature of allowance allocation can make a huge difference to the distribution of the burden from regulation, as well as the cost to the overall economy. Fig. 1 helps convey the different impacts.[5] Here it is assumed that the points of regulation (the entities that must hold and submit allowances) are firms within a competitive industry.

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[3] The ADAGE model and MIT EPPA model adopt a putty-clay treatment for capital, as does the model of Smith et al. [3]. The ADAGE model is described in Ross [6]; the EPPA model is documented in Paltsev et al. [7]. See Smith et al. [3] for details on their model.

[4] To our knowledge, the only other multisector general equilibrium U.S. economy model incorporating optimizing investment decisions at the industry level is that described in Bovenberg and Goulder [2]. The present model extends the earlier model by allowing for a more general treatment of the points of regulation (the earlier model could only impose emissions limits on the coal and oil&gas industries) and by allowing for various potential cost-saving provisions such as offsets and allowance banking and borrowing. It also contains considerably more disaggregation of industries.

[5] For analyses of some of these issues using somewhat different frameworks, see Parry [8] and Burtraw and Palmer [9].

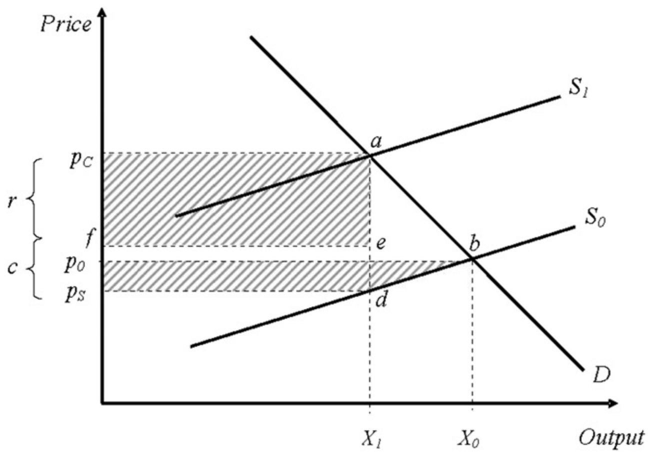

**Fig. 1.** Allowance allocation, rents, and profits.

Consider first the market equilibrium in the absence of regulation. The initial equilibrium price and level of output at the industry level are shown as $p_0$ and $X_0$, respectively. These are determined by the intersection (at point *b*) of the original supply and demand curves $S_0$ and *D*.

Introducing a cap-and-trade system covering emissions from this industry gives firms incentives to reduce emissions no matter whether allowances are purchased (auctioned) or given out freely. In either case, each additional unit of emissions comes at a cost to the emitter, either obliging the firm to purchase an additional allowance, or reducing the number of surplus allowances that the firm can sell. In general, a firm can accomplish the emissions reductions by changing the input mix (for example, switching to less carbon-intensive fuels), installing end-of-pipe equipment, or reducing its level of output. In the figure, it is assumed that the first two adjustments raise production costs by *c* per unit of output. The figure also assumes that the cost per unit of remaining emissions – the allowance price multiplied by emissions per unit of output – is *r*. The policy thus yields the new supply curve $S_1$. In the new equilibrium, output is $X_1$ and the consumer price $p_C$ exceeds the original marginal supply cost by $c+r$.

### 2.1. *Auctioned allowances*

If the allowances are introduced through a competitive auction, the policy will generate no rents: they are bid away through competitive bidding for allowances. In this case, the loss of producer surplus is the shaded trapezoid $p_0bdp_S$, while the loss of consumer surplus is $p_Cabp_0$. The shaded rectangular area $p_Caef$ represents the revenue that the government receives from the allowance auction. These revenues can benefit taxpayers to the extent that they reduce the government's reliance on other taxes. Alternatively, the revenues $p_Caef$ can be used to pay for additional public spending, in which case the general public benefits from the goods or services provided.

### 2.2. *Freely allocated allowances*

If the allowances are introduced through free allocation, the distribution of impacts between producers and taxpayers is fundamentally different. In this case the shaded rectangle $p_Caef$ represents rents to producers rather than revenues to the government. In the figure, these rents are about three times as large as the *gross* loss of producer surplus (the loss before considering the rents) represented by the shaded area $p_0bdp_S$. Thus, in this figure, free allocation enables the firm to enjoy a higher profit than in the absence of regulation.[6]

### 2.3. *Combining auctioning and free allocation*

Policy choices are not limited to the cases of 100% auctioning and 100% free allocation: another option is combining free allocation and auctioning. For the industry depicted in the diagram, industry profits would be preserved if about a third of the allowances were given out free, thus enabling the firm to enjoy about a third of the potential rents. The rest of the

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[6] An analogy with imperfectly competitive markets yields further intuition for this result. Even if a marginal reduction in quantity would increase industry profits by raising the price charged on inframarginal units, perfectly competitive firms by definition are unable to withhold output to realize these profit increases. Imperfectly competitive firms, by contrast, can increase profits by reducing output relative to the level under perfect competition. The imposition of the emissions cap causes firms to reduce output much as a cartel would, which works toward higher profits.

allowances could be auctioned out. As indicated below, auctioning confers some potential advantages in terms of cost-effectiveness.

The amount of free allocation necessary to compensate firms for the costs of complying with the program depends on the extent to which firms can shift to consumers the burden of regulation. This in turn depends on the elasticity of supply relative to the elasticity of demand. A higher relative elasticity of supply implies a larger pass-through of compliance costs into producer prices and a smaller gross loss of producer surplus. It also implies larger potential rents relative to the gross loss of producer surplus, which in turn means that less free allocation (or rents to be retained by firms) is needed to maintain profits. A second factor is the extent of required abatement: at low levels of abatement, permit rents $p_C aef$ are large relative to the gross loss of producer surplus $p_0 bdp_S$, which suggests that relatively few free allowances will be needed to preserve profit. On the other hand, low required abatement generally is associated with lower allowance prices, which means that, other things equal, more allowances must be freely offered to provide sufficient value to preserve profit. In the numerical model employed in this paper, we vary parameters that relate to each of these factors.

### 2.4. Trade-offs between political feasibility and cost-effectiveness

Free allocation may have attractions in terms of political feasibility. By allowing producers to retain the rents created by the cap-and-trade system, free allocation not only can preserve profits but indeed can cause profits to rise. This protection of profits can help build political support from energy-related industries.[7] On the other hand, auctioning has a potential advantage over free allocation in terms of cost-effectiveness. Auction proceeds can be used to finance cuts in pre-existing distortionary taxes; this avoids some of the excess burden or efficiency loss associated with these taxes. In contrast, in the case of free allocation the government forgoes this revenue source and, other things equal, must rely more on ordinary, distortionary taxes (such as income, sales, or payroll taxes) to meet its expenditures, which raises policy costs. Thus, free allocation is at a disadvantage in terms of cost-effectiveness.

This suggests a trade-off between enhancing political feasibility (through free allocation) and maximizing cost-effectiveness (through auctioning). The trade-off might not be severe, however. If (as suggested by the graph) profits can be maintained through free allocation of a relatively small fraction of the allowances, then a significant amount of auctioning is consistent with profit-preservation. In these circumstances the sacrifice of potential revenue would be considerably smaller than in the case of 100% free allocation, and thus the sacrifice of cost-effectiveness need not be large—if the revenues from the auction are used to finance cuts in distortionary taxes.

## 3. The model

We employ an intertemporal general equilibrium model of the U.S. economy with international trade. This model builds on the graphical analysis by introducing the time dimension and allowing for general equilibrium interactions across industries.[8] The model generates paths of equilibrium prices, outputs, and incomes for the U.S. and the rest of the world under specified policy scenarios. The key agents are producers of various goods and services, a representative household, and the government. The model captures the interactions among these agents, whose actions generate supplies and demands for various commodities and productive factors. It solves for all variables at yearly intervals beginning in the benchmark year 2005. We focus on policy impacts through the year 2030.[9]

The model combines a fairly realistic treatment of the U.S. tax system with a detailed representation of energy production and demand. Details on the tax system are important for recognizing the significance of alternative ways to “recycle” auction revenues to the economy. Details on energy production and demand are important for gauging the industry impacts of cap and trade, given the major contributions of various energy uses to emissions of carbon dioxide and other greenhouse gases.

### 3.1. Producer behavior

The model divides U.S. production into the 24 industry categories listed in Table 1. This division gives particular attention to energy-related industries, as it identifies separately oil and natural gas extraction, coal mining, electricity

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[7] The experiments considered in this paper focus on compensating the owners of capital in each industry. Targeting compensation toward capital owners is important to the political feasibility of the bill insofar as the recipients constitute concentrated, well-organized interest groups. Allowance allocation could be employed to enhance political feasibility in other ways, for instance by targeting dislocated workers or vulnerable consumer groups. Our model is not well suited to assessing these issues because it lacks labor adjustment costs or unemployment, and contains only one representative household. For an analysis of recent cap-and-trade proposals that investigates distribution across regions and income groups, see Burtraw et al. [10].

[8] A more detailed description of our model is available in an appendix on JEEM’s onlive archive of supplementary material, which can be accessed at http://aere.org/journals.

[9] We need to perform simulations for a time-interval stretching beyond 2030 to generate long-term expectations for the model’s agents, who face infinite planning horizons. To derive the necessary long-term information, under each policy experiment we first calculate steady-state (terminal) conditions and then employ those conditions in performing simulations over an interval of 80 years, by which time the economic path has converged very close to the steady-state (balanced) growth path.

**Table 1**
Net output by industry in reference case, 2009.[a]

| Industry | Net output | Pct of total net output |
|---|---|---|
| Oil&gas extraction | 329.6 | 1.2 |
| Coal mining | 44.9 | 0.2 |
| Coal-fired electricity generation | 66.3 | 0.2 |
| Other fossil electricity generation | 55.5 | 0.2 |
| Non-fossil electricity generation | 45.0 | 0.2 |
| Electric transmission/distribution | 422.9 | 1.5 |
| Natural gas distribution | 153.4 | 0.5 |
| Petroleum refining | 424.5 | 1.5 |
| Agriculture | 442.6 | 1.6 |
| Non-coal mining | 57.3 | 0.2 |
| Water utilities | 45.0 | 0.2 |
| Construction | 1767.2 | 6.2 |
| Food/tobacco | 825.7 | 2.9 |
| Textiles | 219.7 | 0.8 |
| Wood/paper products | 434.0 | 1.5 |
| Chemicals | 1177.6 | 1.5 |
| Primary metals | 266.9 | 0.9 |
| Machinery | 2364.6 | 8.3 |
| Motor vehicle production | 930.0 | 3.3 |
| Transportation | 836.9 | 2.9 |
| Railroads | 102.5 | 0.4 |
| Information | 1127.1 | 4.0 |
| Services | 13,642.6 | 47.8 |
| Owner occupied housing | 2729.8 | 9.6 |
| **Total** | 28511.4 | 100.0 |

[a] In billions of 2005 dollars.

transmission and distribution, coal-fired electricity generation, non-coal fossil fuel electricity generation, non-fossil fuel electricity generation, petroleum refining, and natural gas distribution.[10] The specification of energy supply incorporates the nonrenewable nature of crude petroleum and natural gas and the transitions from conventional to backstop fuels.

*General specifications*: In each industry, a nested production structure is employed with constant-elasticity of substitution (CES) functional forms at each nest. In all industries except the oil and natural gas extraction industry (discussed further below), production exhibits constant returns to scale: each industry is therefore modeled as a representative firm. Each industry produces a distinct output ($X$), which is a function of the inputs of capital ($K$), labor ($L$) an energy composite ($E$), a non-energy (or materials) composite ($M$), and the level of investment ($I$)[11]:

$$X = f(K, g(L, h(E, M))) - \phi(I/K)I \tag{1}$$

The energy composite is made up of the outputs of the nine energy industries, while the materials composite consists of the outputs of the other industries:

$$E = E(\bar{x}_{1a} + \bar{x}_{1b}, \bar{x}_2, \ldots, \bar{x}_8) \tag{2}$$

$$M = M(\bar{x}_9, \ldots, \bar{x}_{24}) \tag{3}$$

where $\bar{x}_i$ is a composite of domestically produced good from industry $i$ and its foreign counterpart.[12] Industry indices correspond to those in Table 1.[13]

The model incorporates technological change exogenously in the form of Harrod-neutral (labor-embodied) technological progress at the rate of 2% per year.[14]

*Adjustment costs*: Among economy-wide general equilibrium models, this model is unique in its treatment of industry-level investment and capital dynamics. In each industry, managers choose the level of investment to maximize the value of the firm. The investment decision takes account of the adjustment (or installation) costs represented by $\phi(I/K)I$ in Eq. (1).

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[10] Non-coal fossil fuel generators primarily consist of natural gas fired generators. Non-fossil fuel generators include nuclear, hydro, solar, and wind generators.

[11] In each industry, capital ($K$) is a CES aggregate of structures and equipment.

[12] The functions $f$, $g$, and $h$, and the aggregation functions for the composites $E$, $M$, and $\bar{x}_i$ are CES and exhibit constant returns to scale.

[13] Indices 1a and 1b represent the oil&gas and synfuels industries, respectively. Synfuels are a "backstop technology"—a perfect substitute for oil&gas. Only the oil&gas industry is shown in Table 1 because synfuels production does not begin until 2025.

[14] Although each industry enjoys technological progress, there is no explicit modeling of the invention of relatively new and evolving technologies such as carbon capture and storage. Such technologies may become very important in the longer run, but are less likely to be critical during the time-interval 2009–2030 on which we focus.

$\phi$ is a convex function of the rate of investment, $I/K$

$$\phi(I/K) = \frac{(\xi/2)(I/K - \delta)^2}{I/K} \tag{4}$$

where $\delta$ is the rate of economic depreciation of the capital stock and $\xi$ is the marginal adjustment cost.[15] Adjustment costs imply that capital is imperfectly mobile across sectors, which, as mentioned, allows the model to capture the different impacts of policy interventions on the profits of various industries. The law of motion for capital stocks for each industry is given by $K_{s+1}=(1-\delta)K_s+I_s$.

We capture the nonrenewable nature of oil and gas stocks by setting a fixed quantity of resources that limits the total amount that can be extracted cumulatively over all periods. Productivity in the oil&gas industry is specified as a decreasing function of cumulative production to date so that extraction becomes more costly as the most accessible reserves are depleted. In making profit-maximizing extraction decisions, oil&gas producers account for the effect of current production on future production costs. The domestic price of oil&gas is given by the exogenously specified world price of oil gross of tariffs. The model includes a "backstop fuels industry" that provides a perfect substitute for oil&gas. The technology for producing backstop fuels on a commercial scale is assumed to become known only in the year 2025. We assume that backstop fuels have the same carbon content as oil&gas.[16]

*Profits and the value of the firm*: For a firm in a given industry and given period of time, profits can be written as

$$\pi = (1-\tau_a)[\overline{p}X - w(1+\tau_L)L - EMCOST - iDEBT - TPROP + LS + p_c\alpha A] + \tau_a(DEPL + DEPR) \tag{5}$$

where $\tau_a$ is the corporate tax rate (or tax rate on profits), $\overline{p}$ is the per unit output price net of output taxes, $w$ is the wage rate net of indirect labor taxes, $\tau_L$ is rate of the indirect tax on labor, *EMCOST* is the cost to the firm of energy and materials inputs, *i* is the gross-of-tax interest rate paid by the firm, *DEBT* is the firm's current debt, *TPROP* is property tax payments, *LS* is a lump-sum receipt (if applicable) by the firm, *DEPL* is the current gross depletion allowance, and *DEPR* is the current gross depreciation allowance. $p_c$ denotes the price per ton of carbon emissions, $A$ denotes the economy-wide total allowances (or the aggregate emission cap), and $\alpha$ represents the share of total allowances given free to the given industry.

In the presence of a binding aggregate emissions cap, $p_c$ will be positive. From the firm's point of view, $p_c\alpha A$, the total value of the allowances it receives free, is a lump-sum payment. Therefore the receipt of free allowances does not alter marginal costs or returns. Free allowances thus have no direct effect on a firm's choices of labor, intermediate inputs, and investment, although they do raise a firm's profits.[17]

Based on the cash-flow identity linking sources and uses of the firm's revenues, one can derive the following expression for the value of the firm:

$$V_t = \sum_{s=t}^{\infty} \left[\frac{1-\tau_e}{1-\tau_v} DIV_s - VN_s\right] \mu_t(s) \tag{6}$$

where $\mu_t(s) \equiv \Pi_{u=t}^{s}[1+(r_u/1-\tau_v)]^{-1}$ and $\tau_v$ is the tax rate on capital gains. Eq. (6) indicates that the equity value of the firm is the discounted sum of after-tax dividends net of new share issues. In each period, managers choose investment levels as well as cost-minimizing inputs of labor and intermediate inputs to maximize this equity value.

### 3.2. Household behavior

Household behavior stems from decisions by an infinitely-lived representative agent that chooses consumption, leisure, and savings in each period to maximize its intertemporal utility subject to its budget constraint. The representative household has constant-relative-risk-aversion utility over "full consumption" $C$. $C$ is a CES composite of consumption of goods and services $\tilde{C}$ and leisure $\ell$. Final good consumption $\tilde{C}$ is a Cobb–Douglas composite of 17 consumer goods, $\overline{C}_i$.[18] In turn, each consumer good $\overline{C}_i$is a CES composite of domestically and foreign produced goods. At each nest in the household's demand system, the household allocates its expenditure to obtain the composite associated with that nest at minimum cost. The household maximizes utility subject to an intertemporal budget constraint.

### 3.3. The government sector

The government collects taxes, distributes transfers, purchases goods and services, and hires labor. Overall government expenditure is exogenous and increases at a constant rate, $g$, equal to the steady-state growth rate of the model. In the benchmark year, 2005, the government deficit is 1.9% of GDP. In the reference (*status quo*) simulation, the deficit-GDP ratio is approximately constant.

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[15] $\phi$ captures the notion that there is an output loss associated with installing new capital as inputs are diverted to install the new capital.

[16] In reality, some potential backstops (e.g., shale oil) have higher carbon content than others (e.g., biofuels).

[17] Free allowances can affect economic output through their impacts on the government's budget, though the numerical simulations reported in Section 5 indicate that these fiscal impacts are small.

[18] Consumer goods are produced by combining outputs from the 25 industries in fixed proportions.

In the policy experiments in this paper, we require that the real deficit and real government spending follow the same path as in the reference case. The government's real tax receipts under a policy change thus must be the same as in the reference case. As discussed below, some cap-and-trade systems would tend to raise revenues, while others would sacrifice revenue. Revenue-neutrality is accomplished through adjustments to the marginal rates of individual income taxes or lump-sum adjustments to individual taxes.

### 3.4. Foreign trade

Except for oil&gas imports, which are perfect substitutes for domestically produced oil&gas, imported intermediate inputs and consumer goods are imperfect substitutes for their domestic counterparts. Import prices are exogenous in foreign currency, but the domestic currency price changes with changes in the exchange rate. Export demands are modeled as functions of the foreign price of U.S. exports and the level of foreign income (in foreign currency). The foreign price is the price in U.S. dollars plus tariffs or subsidies, converted to foreign currency through the exchange rate. We impose the assumption of zero trade balance at each period of time; an exchange rate adjusts in each period to achieve balanced trade.

### 3.5. Cap-and-trade policies

The model offers a flexible treatment of cap and trade, allowing for alternative specifications as to the time-profile of the overall cap, the points of regulation, and the nature of allowance distribution.

The variable $A_t$ (included in Eq. (5) above) represents the total tons of emissions allowed (or total allowances circulated) in period $t$ in sectors covered by the cap-and-trade program. In the absence of offsets or provisions for the banking or borrowing of allowances, the endogenous price of $CO_2$ emissions allowances, $p_c$, adjusts to equate in each period aggregate covered-sector emissions $H_t$ with the aggregate supply of allowances $A_t$.

*Points of regulation*: Cap-and-trade policies can differ according to the points of regulation, that is, the entities that must hold and submit allowances to validate the level of emissions they generate within a given compliance period. The model considers both "fully upstream" and "modified upstream" policies. Under a fully upstream policy, allowances are required at the entry points for carbon in the economy: these are the wellhead for oil and natural gas producers and the mine mouth for coal, as well as the port of entry for imports of these fuels. Under a modified upstream policy, the points of regulation are various industrial entities, at least some of which are further downstream from the initial suppliers of carbon to the economy. While nearly any user of carbon-based fuels could be specified as a point of regulation, many recent U.S. cap-and-trade proposals have focused on electric power producers, refiners, and various large industrial emitters of $CO_2$ as points of regulation.

Under the fully upstream policy, fossil fuel suppliers must hold and submit emissions allowances consistent with the emissions implied by the carbon content of each unit of fuel they supply. This requirement functions like a tax on production. For these suppliers, the producer (or net) price of output, $\overline{p}_i$, will reflect the market price of allowances, $p_c$ (since the allowance price is the opportunity cost of emissions)[19]:

$$\overline{p}_i = p_i(1-\tau_{0i})-p_c c_i \tag{7}$$

where $p_i$ is the gross price of output, $\tau_{0i}$ represents any pre-existing ad valorem output taxes, and $c_i$ is the carbon content per unit of fuel for the industry in question. Thus, under the fully upstream policy, the price of allowances functions like a per unit tax on the output of fuel producers.

Under the modified upstream policy, industrial users of carbon must hold and submit emissions allowances corresponding to the carbon content of each good they purchase. In this case the cost of emissions allowances is a charge added to the price of carbon-based fuels used as inputs to production. Let $p_{kj}$ represent the price of fossil fuel input $k$ to industry $j$. Then

$$p_{kj} = p_k(1+\tau_{kj})+d_j p_c c_k \tag{8}$$

where $p_k$ is the pre-tax price of fuel $k$, $\tau_{kj}$ represents any pre-existing intermediate input taxes on fuel $k$ used by industry $j$, and $d_j$ is a dummy variable that equals one if industry $j$ is a point of regulation and zero otherwise.

*Allowance allocation*: The model can consider any combination of auctioning and free allocation of allowances, including the limiting cases of 100% auctioning and 100% free allocation. In addition, it is flexible as to how the free allowances are allocated across various industries.[20]

Recall from Eq. (5) in Section 3.1 above that $\alpha_i A$ is the number of allowances allocated freely to industry $i$ (in a given time period). Producers can use these emissions allowances themselves or sell them at the market price to other industries covered under the cap. Eq. (5) indicates that from the firm's point of view, allowances received free are a lump-sum

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[19] As indicated in Section 2, the opportunity cost of emissions is the same no matter whether the firm receives allowances free or must purchase them at an auction.

[20] In this paper, we only consider *exogenous* free allocation. We do not examine free allocation that depends on firms' ongoing behavior, such as output-based free allocation.

transfer: they do not affect firms' marginal costs of production. Thus, free allocation has no direct effect on firms' pricing or output decisions.[21]

*Banking and borrowing*: Provisions for banking and borrowing allow firms to equate marginal abatement costs (in present value) over time, which reduces the present value of abatement costs. Under a system with fully functioning banking and borrowing, in market equilibrium the discounted allowance price will be the same in every period within the interval where banking and borrowing is allowed [11]. In simulations of cap-and-trade systems involving banking and borrowing, we introduce this condition. In addition, we relax the condition that in any given period, aggregate emissions must not exceed the current emissions cap. We replace this condition with the requirement that the cumulative emissions over the interval that allows banking and borrowing must not exceed the equal cumulative emissions cap over that interval.

### 3.6. Equilibrium

An equilibrium in a given period is defined as a set of prices and quantities such that (1) labor supply equals its demand, (2) supply meets demand in each industry, (3) savings equals investment, and (4) government expenditure equals tax revenue less the exogenously specified government deficit. Under simulations of cap-and-trade policies, we also require market clearing in the emissions allowance market.

Market clearing is achieved in each period through adjustments in output prices, the market interest rate, and lump-sum taxes or tax rates.[22] In simulations of cap-and-trade policies, the price of carbon adjusts such that the aggregate demand for allowances (given by aggregate emissions from covered sectors) equals the aggregate supply each period. If banking and borrowing is specified, the discounted price of carbon must be equal across periods, as discussed above, and an intertemporal demand–supply requirement must be satisfied: cumulative demand for allowances over a specified interval must equal the cumulative supply of allowances over that interval. We impose perfect foresight on all agents' expectations.[23]

## 4. Data and parameters

Complete data and parameter documentation is in the appendix at the JEEM online archive. Here we sketch some main components and their sources.

### 4.1. Data

Industry input and output flows were obtained primarily from the 2005 input–output tables from the U.S. Department of Commerce's Bureau of Economic Analysis (BEA). These tables were also the source for consumption, investment, government spending, employment, import, and export values by industry. Data on capital stocks by industry derive from BEA tables on the net stock of structures and equipment for each industry, except for the four electricity sectors. The BEA industry capital data do not split out these industries. For these industries we apply data from the Energy Information Administration of the U.S. Department of Energy and the Federal Energy Regulatory Commission (FERC).[24] From the U.S. Environmental Protection Agency we obtained data on the energy factors and carbon contents of oil, natural gas, and four main types of coal. From this information we derive carbon dioxide emissions per unit of oil, natural gas, and coal.

### 4.2. Parameters

Production function elasticities of substitution for the model were derived from estimates by Dale Jorgenson and Peter Wilcoxen. We translated the Jorgenson–Wilcoxen estimates of parameters for translog cost functions into elasticities of substitution parameters to make them compatible with the CES form of our model. The capital adjustment cost parameters are based on Summers [13].[25] Other important parameters apply to the household side of the model. The elasticity of

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[21] However, free allocation can affect prices and output by way of impacts on the fiscal system. These general equilibrium effects are discussed in Section 5.

[22] By Walras's Law, the required number of equilibrating variables is one less than the number of equilibrium conditions. The numeraire is the nominal wage.

[23] To solve for the equilibrium, we apply a two step algorithm similar to that of Fair and Taylor [12]. First we solve the model in each period for the market clearing prices, interest rates, and taxes given a set of expectations. We then iterate until we find expectations consistent with the intertemporal equilibrium condition of perfect foresight.

[24] Specifically, we calculate the average installation cost (net of depreciation) of 1 MW of nameplate capacity by vintage for different generating technologies. We apply these average historical cost figures to the distribution of 2005 generating capacity by generator type and vintage and aggregate by fuel to obtain capital stocks for our generation industries. The residual stocks of structures and equipment implied by BEA aggregates for the electric power industry are assigned to Electric Transmission and Distribution. Installation cost data are obtained from 2005 FERC Form 1. Year 2005 capacity data are obtained from EIA form EIA-860 for 2006.

[25] Summers's adjustment cost estimates are based on the assumption that adjustment costs are variable costs that are convex in the rate of investment, as in our model. More recent capital adjustment cost estimates downplay the variable cost component and emphasize fixed costs of adjustment. In future work we would like to obtain and apply estimates that include both fixed and variable components of adjustment costs.

substitution in consumption between goods and leisure, $\upsilon$, is set to yield a compensated elasticity of labor supply of 0.4.[26] The intertemporal elasticity of substitution in consumption, $\sigma$, equals 0.5.[27] The intensity parameter $\alpha_C$ is set to generate a ratio of labor time to the total time endowment equal to 0.44. These parameters imply a value of 0.19 for the interest elasticity of savings between the current period and the next.

## 5. Results

Our model begins its simulation in 2005 with the cap-and-trade policy being announced in 2009 and implemented in 2012. Because agents are forward-looking, policies begin to have impacts at the time of their announcement.

### 5.1. Reference case

To analyze cap-and-trade's impacts, we first perform a reference case simulation. This simulation assumes business-as-usual conditions and forms the reference path against which we measure the effects of policy shocks. Table 1 shows the levels of real output of each industry in the reference case in 2009, in billions of 2005 dollars.

### 5.2. Cap-and-trade policies—central case specifications

The cap-and-trade policies focus on carbon dioxide ($CO_2$) emissions, which accounted for 86% of U.S. greenhouse gas emissions (in $CO_2$ equivalents) in 2007, the latest year for which public estimates are available. The other greenhouse gases are not capped. Fig. 2 displays the economy-wide emissions of $CO_2$ that result from the model in the reference case and under cap and trade. The emissions cap requires a reduction in emissions of about 3% from 2005 levels by 2012, 17% by 2020, and 42% by 2030. This time-profile of the cap matches that proposed in HR 2454 (Waxman–Markey), which was passed on June 26, 2009 by the U.S. House of Representatives.[28]

#### 5.2.1. Points of regulation

The points of regulation represent a key design element of any cap-and-trade system. Our central case involves a modified upstream approach. (In Section 5.4 below we compare this case with a fully upstream policy.) Electricity generators, petroleum refiners, natural gas pipelines, and some industries that use carbon-based fuels intensively (chemical and primary metals manufacturers) are required to hold permits sufficient to cover their carbon emissions.[29] This roughly corresponds to the industries identified as points of regulation in HR 2454.[30]

#### 5.2.2. Allowance allocation

We assume that allowances are allocated (either auctioned or given out free) on an annual basis. In this central case, we also assume that allowances can only be applied to emissions in the year in which they are allocated: they cannot be banked for use in future years, nor can they be borrowed (used in years prior to the year in which they are allocated).

As mentioned above, the relative reliance on auctioning and free allocation, as well as the division of free allowances across industries, critically affects the impacts of cap and trade on profits of various industries. Indeed, the choice of allocation method is more critical to the incidence across industries of a cap-and-trade system than the choice of points of regulation.

Our central case simulations compare the following allocation approaches:

- *100% auctioning*: All allowances are auctioned to the industries selected as points of regulation.
- *Profit-preserving free allocation*: Some allowances are freely allocated to the eight industries that would experience the most significant profit losses under 100% auctioning.[31] Just enough allowances are freely allocated to these industries to preserve the present value of their profits over the interval 2009–2030. The remaining allowances are auctioned.
- *100% free allocation*: All allowances are freely allocated to the eight industries that would experience the most significant profit losses under 100% auctioning. Each industry's share of the total allowances offered free in each year corresponds to its share of the free allowances offered in the case of profit-preserving allocation.

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[26] This lies midway in the range of estimates displayed in the survey by Russek [14].

[27] This value falls between the lower estimates from time-series analyses (e.g., Hall [15] and the higher ones from cross-sectional studies (e.g., Lawrance [16].

[28] After 2030, we allow the cap to increase at the model's steady-state growth rate of 2% per year, so that the ratio of emissions to aggregate output becomes constant in the long run and the model attains balanced growth.

[29] Coal and oil&gas inputs to the production of the investment good composite ($I$) are also subject to the emissions cap. For details, see the model description in the appendix in the JEEM online archive.

[30] The points of regulation in HR 2454 accounted for 85% of US greenhouse gas emissions in $CO_2e$ terms in 2005. Our modified upstream policy covers 88% of US $CO_2$ emissions in the benchmark year of 2005.

[31] We choose the eight industries that under 100% auctioning would experience the largest percentage reductions in profit over the interval 2009–2030. We exclude the water utilities industry (which otherwise would rank in the top eight) from consideration because of its small size and low emissions relative to the others.

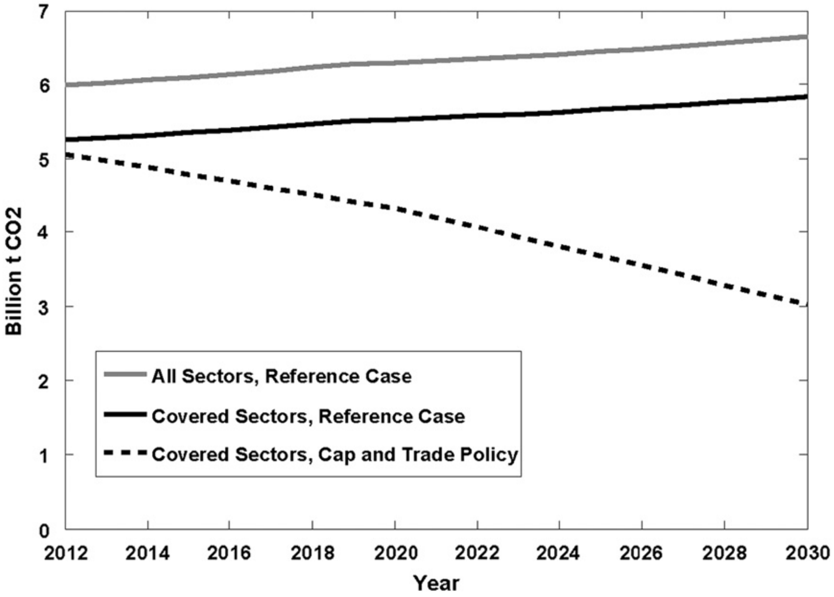

**Fig. 2.** Covered sector and economy-wide carbon dioxide emissions, 2012–2030.

It is worth emphasizing that the potential burden of cap-and-trade policies is not confined to the industries selected as points of regulation. Generally these industries will shift some of the burden forward to their customers and backward to their suppliers. Some of the industries most vulnerable to cap and trade are outside the points of regulation. Thus the set of industries receiving free allowances in the profit-preserving free allocation case includes industries that are not points of regulation. These additional industries benefit from the free allowances by selling their allowances to the industries that are points of regulation.

### 5.2.3. Revenue use

In the absence of the income tax rate adjustments, the 100% auctioning case and profit-preserving free allocation cases would be revenue-augmenting: the auction revenue they bring in more than compensates for adverse revenue impacts from policy-induced reductions in the tax base. In contrast, the 100% free allocation case would be revenue-losing: its adverse impact on the tax base[32] is not offset by any auction revenue.

For the 100% auctioning and profit-preserving free allocation cases, we consider two alternative ways of achieving revenue-neutrality: (1) through reductions in personal income taxes and (2) via lump-sum tax rebates to households.[33] In the 100% free allocation case, which generates no auction revenue, revenue-neutrality is achieved through (modest) increases in personal tax rates.

## 5.3. Central case results

### 5.3.1. Limiting cases: 100% auctioning and 100% free allocation

Table 2 shows the impacts of the cap-and-trade policy on the profits in various industries for years 2015 and 2020, for the cases involving 100% auctioning and 100% free allocation. Profit impacts differ dramatically depending on the allocation method.

Under 100% auctioning, the carbon-intensive industries experience significant losses of profit. The magnitudes of these losses are very similar across the two forms of revenue-recycling (personal tax rate cuts and lump-sum rebates). The method of revenue-recycling affects households' labor supply, saving and investment decisions. Although these decisions are important for the overall economy, they tend to be spread across all industries rather than be concentrated in the carbon-intensive industries. Thus, the impact on the carbon-intensive industries is relatively minor, particularly in the

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[32] Although free allocation can preserve profits, cap and trade leads to overall losses of GDP and household income in particular. Hence the loss of tax base.

[33] Of course, cap-and-trade policies need not be revenue-neutral: revenues could be devoted to finance additional government expenditure, including programs to improve energy efficiency. Such alternatives are beyond the scope of the present paper. In our analysis, the lump-sum tax rebate is set equal to the value of emissions allowances auctioned. This is in keeping with recent proposals, which specify household rebates and other outlays as percentages of the gross value of auction revenues, rather than as percentages of auction revenue net of the revenue loss from the reduction in the tax base.

**Table 2**
Percent change in profits by industry under alternative allocation methods.[a]

| **Industry** | **Reference case** | | **Cap and trade policy** | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **100% auction** | | | | **100% free allocation** | |
| | **2015** | **2020** | **2015** | | **2020** | | **2015** | **2020** |
| | | | *Marginal rate cuts* | *Lump-sum rebates* | *Marginal rate cuts* | *Lump-sum rebates* | | |
| Oil&gas extraction | 261.9 | 311.3 | 0.4 | −0.3 | 1.2 | 0.8 | −0.4 | 0.7 |
| Coal mining | 18.1 | 25.3 | −18.8 | −18.6 | −35.3 | −35.0 | 59.4 | 141.4 |
| Coal-fired electricity generation | 18.2 | 25.8 | −11.2 | −11.5 | −29.0 | −28.8 | 68.1 | 148.6 |
| Other fossil electricity generation | 24.7 | 30.3 | 8.8 | 7.8 | 19.8 | 18.8 | 7.9 | 18.8 |
| Non-fossil electricity generation | 27.8 | 38.7 | 9.0 | 8.0 | 25.6 | 24.3 | 8.1 | 24.4 |
| Electric transmission/distribution | 170.1 | 229.2 | −0.7 | −1.3 | −1.9 | −2.3 | 5.2 | 12.8 |
| Natural gas distribution | 21.9 | 29.2 | −0.9 | −0.9 | −2.2 | −2.2 | 6.1 | 14.4 |
| Petroleum refining | 23.2 | 30.4 | −1.2 | −1.9 | −3.6 | −4.1 | 10.6 | 26.1 |
| Chemicals | 122.4 | 164.9 | −0.8 | −1.5 | −2.5 | −3.0 | 7.4 | 17.9 |
| Primary metals | 35.8 | 49.7 | −1.0 | −1.5 | −3.0 | −3.4 | 8.1 | 18.5 |
| Railroads | 41.6 | 56.1 | −1.0 | −1.7 | −2.6 | −3.0 | 4.9 | 12.4 |
| **Other industry average** | 639.0 | 862.0 | 0.1 | −0.8 | −0.2 | −0.9 | −0.8 | −0.9 |

[a] Figures for reference case are in billions of 2005 dollars. Other figures are percentage changes from reference case.

short term.[34] Coal mining and coal-fired electricity generation endure the largest losses, in keeping with the high carbon intensity of their output (from coal mining) or fuel input (for coal-fired electricity generation). Other carbon-intensive industries also experience significant profit losses. Note that the losses of profit are not confined to the points of regulation (electricity generators, petroleum refiners, chemical and primary metals producers, and natural gas distributors). Likewise, some of the points of regulation (in particular, non-fossil electricity generators and other fossil generators) experience increased profits under 100% auctioning. Other fossil generators are primarily natural gas combined cycle plants. The cap and trade policy stimulates substitution away from coal-fired generation (which is exceptionally carbon-intensive) toward other forms of electricity generation. The increased demand for these other generation methods underlies the profit increases in these industries.

Under 100% free allocation, the results are very different. For each of the eight industries that would suffer the largest percentage losses without free allocation or other compensation, 100% free allocation yields increases – and often very large increases – in profit. For coal mining, for example, in 2020 the 35% reduction in profits under 100% auctioning converts to a 141% increase under 100% free allocation. One hundred percent free allocation overcompensates industries by giving them a quantity of allowances whose value exceeds the policy-induced gross loss of producer surplus, as defined in Section 2. To preserve profits, the government needs only to offer firms allowances whose value corresponds to the portion of the policy burden that producers are unable to shift to other industries or to consumers. One hundred percent free allocation grants firms considerably more allowances than this.[35]

Table 3 offers another measure of profit impacts—the percentage change in the present value of profits over the interval 2009–2030. The left pair of columns shows impacts under 100% auctioning (with alternative revenue-replacement methods), while the far-right column shows impacts under 100% free allocation. The numbers follow a similar pattern to that described in Table 2 for the years 2015 and 2020.

### 5.3.2. *Profit-preserving free allocation*

We now examine how much free allocation is necessary to preserve profits (in present value, over the interval 2009–2030) in the eight most vulnerable industries. The middle columns of Table 3 indicate the needed free allowances as a percentage of the total allowances under the cap and trade system.[36] The coal mining and coal-fired electricity generation industries require

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[34] In the longer term, the choice of recycling method has a more perceptible impact on industry profits. Recycling through cuts in marginal tax rates tends to stimulate investment more than lump-sum recycling does. As a result, firms tend to enjoy larger profit increases, or suffer smaller losses, under the former recycling method.

[35] In Phase I of the European Union's Emissions Trading Scheme, more than 95% of the emissions allowances were freely allocated to firms. Several interested parties have voiced concerns that this might have led to windfall profits. Ellerman and Joskow [17] point out, however, that the impact of the EU ETS on profits in the electricity sector is difficult to gauge because of coincident changes in natural gas prices as well as some countries' regulations preventing utilities from raising electricity prices in parallel with allowance prices (the marginal cost of emissions).

[36] General equilibrium interactions might cause a given industry's requirement to depend on whether other industries are being offered free allowances. The numbers shown are the required allowances when each of the eight industries simultaneously receives the needed free allowances. In other simulations we have calculated the required profit-preserving free allocation when free allocation is just offered to one industry. From such simulations the requirements for any industry are very close to those reported for that industry in the table. Although a given industry's requirements for profit-preservation appear relatively insensitive to the amount of free allocation going to other industries, they are very much affected by other general

**Table 3**
Profit and GDP impacts under alternative allocation methods.[a]

| **Industry** | **100% auctioning** | | **Profit-preserving free allocation** | | **100% free allocation** |
|---|---|---|---|---|---|
| | *Marginal rate cuts* | *Lump-sum rebates* | *Marginal rate cuts* | *Lump-sum rebates* | |
| **Percentage change in profits[b]** | | | | | |
| Coal mining | −28.7 | −28.0 | 0 (3.2) | 0 (3.2) | 178.8 |
| Coal-fired electricity generation | −28.4 | −27.8 | 0 (3.2) | 0 (3.2) | 177.2 |
| Petroleum refining | −4.7 | −4.3 | 0 (0.7) | 0 (0.7) | 29.4 |
| Chemicals | −3.2 | −2.9 | 0 (2.4) | 0 (2.4) | 20.7 |
| Primary metals | −3.5 | −3.0 | 0 (0.8) | 0 (0.8) | 22.2 |
| Railroads | −2.5 | −2.0 | 0 (0.6) | 0 (0.6) | 15.6 |
| Electric transmission/generation | −2.5 | −2.0 | 0 (2.5) | 0 (2.5) | 15.5 |
| Natural gas distribution | −2.8 | −1.4 | 0 (0.3) | 0 (0.3) | 17.5 |
| All industries above | −5.0 | −4.5 | 0 (13.7) | 0 (13.7) | 31.6 |
| All other industries | 0.1 | 0.4 | 0.2 | 0.4 | 0.4 |
| All industries | −0.2 | 0.0 | 0.2 | 0.4 | 2.7 |
| **GDP cost[c]** | 0.472 | 0.808 | 0.516 | 0.806 | 0.788 |

[a] In each policy experiment, revenues are recycled through marginal tax rate adjustments.

[b] Percentage change in the present value of profits over the interval 2009–2030. In the columns labeled "Profit-Preserving Free Allocation" the numbers in parentheses indicate, for each of eight industries, the percentage of economy-wide allowances that need to be freely allocated to preserve profits.

[c] Percentage change in the present value of GDP over the interval 2009–2030.

the largest number of free allowances: each would need about 3% of all the covered emissions (or all the allowances) in the system. Coal-fired electricity generators would receive about 24% of their needed allowances free.

The other vulnerable industries require smaller shares of the system's total allowances, and their free allowances represent smaller fractions of their own emissions. Importantly, the allowances needed by these industries together total less than 14% of the cap-and-trade system's allowances. Thus, these simulations suggest that over 86% of the allowances could be auctioned out.[37] Section 2 indicated that the share of allowances that must be offered free to sustain profits is smaller, the greater the ability of firms to shift forward the costs of emissions abatement. This ability increases with the elasticity of supply and decreases with the elasticity of demand. Our numerical results indicate that, in general, industries are capable of shifting much of the policy costs – in particular, that supply elasticities are large relative to demand elasticities. The supply elasticities reflect the capital adjustment cost parameters in the model, while the demand elasticities reflect elasticities of substitution in production.

Table 4 provides a closer look at the relative contributions to emissions of the various industries under the cap and trade policy, and the allowances required for profit-preservation, both in levels and as a percentage of the economy-wide total.

The fact that profit-preservation is consistent with auctioning over 86% of the allowances has important implications for the overall policy costs. As discussed in Section 2, 100% auctioning has the greatest potential for cost-effectiveness because auction proceeds can be used to finance cuts in distortionary taxes, thereby avoiding some of the efficiency costs of those taxes. To the extent that the government utilizes free allocation, it foregoes this opportunity. In our simulations, 100% auctioning enables the government to simultaneously reduce marginal tax rates on labor income by 0.21 percentage points and on capital income by 0.32 percentage points. In contrast, 100% free allocation compels the government to raise these marginal rates by 0.64 percentage points and 0.97 percentage points, respectively.[38]

The bottom row of Table 3 reveals the significance of the alternative allocation methods for policy costs, here expressed as the reduction, relative to the reference case, in the present value of GDP over the interval 2009–2030. The most cost-effective case is 100% auctioning with auction revenues used to finance cuts in the marginal rates of personal income taxes. In this case, cap and trade has a GDP cost of about 0.47%. The least cost-effective cases are those in which no policy-generated revenue is used to finance cuts in marginal rates of individual income taxes. These include the case of 100% free

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(*footnote continued*)
equilibrium effects—namely, interactions with the tax system. A cap-and-trade program affects the government's tax revenues, thereby necessitating changes in existing taxes to finance expenditures. In addition, by causing higher prices of energy-intensive goods and services, cap and trade imposes a tax on factors of production—a tax-interaction effect. These interactions with the fiscal system have impacts on returns to labor and capital throughout the economy, affecting profits of all industries (see [2]) and the allowances required for profit-preservation. Evaluating these effects requires a general equilibrium analysis.

[37] Initially, HR 2454 makes relatively little use of auctioning. In 2020, for example, roughly 40% of allowances are allocated freely to firms and another 30% are allocated free to households. The free allocation is either direct or by way of local electricity distribution companies that must pass-through the allowance value through cuts in electricity prices. The use of auctioning increases over time. By 2030, roughly 70% of allowances are to be auctioned.

[38] Another possible use of auction revenues is to finance additional government spending. Farrow [18] and Parry and Oates [19] offer analyses of the efficiency implications when environmental policy revenues are employed in this way. In HR2454, however, most of the auction revenues raised when auctioning becomes the dominant allocation method are designated for financing lump-sum rebates rather than reductions in marginal rates.

**Table 4**
Emissions reductions by industry and allocations necessary to preserve present value of after-tax profits 2009–2030.[a]

| **Industry** | Cumulative $CO_2$ emissions 2009–2030 | | | Percent change in profits under 100% auctioning | Allowances required for compensation | |
|---|---|---|---|---|---|---|
| | Reference | Cap and trade | Percent reduction | | Total 2009–2030 | Percent of total allowances |
| Coal mining | 3.7 | 2.5 | −31.6 | −28.7 | 2.5 | 3.2 |
| Coal-fired electricity generation | 24.8 | 10.5 | −57.5 | −28.7 | 2.5 | 3.2 |
| Petroleum refining | 34.0 | 30.6 | −9.9 | −4.7 | 0.5 | 0.7 |
| Chemicals | 10.8 | 8.6 | −20.2 | −3.2 | 1.9 | 2.4 |
| Primary metals | 9.3 | 4.5 | −51.2 | −3.5 | 0.6 | 0.8 |
| Railroads | 0.0 | 0.0 | −1.8 | −2.5 | 0.5 | 0.6 |
| Electric transmission/generation | 0.0 | 0.0 | 0.0 | −2.5 | 1.9 | 2.5 |
| Natural gas distribution | 7.9 | 7.1 | −10.1 | −2.8 | 0.3 | 0.3 |
| Subtotal | 95.1 | 67.4 | −29.2 | −5.0 | 10.7 | 13.7 |
| **Other industry average** | 24.3 | 24.1 | −0.7 | 0.1 | n.a | n.a |

[a] Emissions are in millions of metric tons. Profit impacts and allowance requirements are from simulations in which auction revenues are used to finance reductions in the marginal rates of individual income taxes.

allocation and the case of 100% auctioning, with revenues recycled through lump-sum rebates. In these cases, the GDP costs are very similar – 0.79% and 0.81%, respectively – and about 65% higher than in the most cost-effective case.

The table also shows the GDP costs in the case of profit-preserving free allocation, that is, where just enough allowances (about 14% of the total) are given out free to preserve profits in the eight most vulnerable industries. Again the GDP costs depend on the method of revenue recycling. Importantly, preserving profits need not substantially raise the GDP costs. When the revenues from the auction component of this policy are used to finance marginal income tax rate cuts, the GDP costs are increased by just 9% relative to the most cost-effective case. The costs in this case are about a third lower than the previously mentioned cases involving no marginal rate cuts. If instead the revenues from the auction component are recycled through lump-sum rebates, the GDP costs are very close to those of the other cases involving no marginal rate cuts.[39]

Two key messages emerge from these results. First, relatively little free allocation suffices to prevent profit losses in major carbon-supplying and carbon-using industries. Second, relative to the most cost-effective case involving no profit-preservation, the added GDP cost of preventing profit losses is small, provided that revenues are recycled through marginal income tax cuts. We will see that these results are quite robust to the alternative policy designs examined below.

The finding that relatively few allowances are needed to preserve profits is consistent with earlier findings by Bovenberg and Goulder [2] and Smith and Ross [20]. These studies considered only upstream cap-and-trade systems and concentrated on preserving profits in the coal mining and oil&gas extraction industries. Bovenberg and Goulder found that freely allocating about 10% of the allowances sufficed to preserve profits in those industries. Smith and Ross found that 9–21% would be sufficient to preserve these industries' profits. In a subsequent study, Smith et al. [3] claimed that considerably higher fractions of allowances must be freely allocated to preserve profits.[40]

### *5.4. Alternative program designs*

The cap-and-trade program described thus far excludes several potential cost-reducing features, such as provisions for offsets and for allowance banking and borrowing—features included in many recent proposals. We now explore how such provisions affect the impact of alternative allowance allocation approaches.

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[39] Employment impacts tend to correlate with the GDP impacts. In particular, in the cases of 100% auctioning as well as 100% free allocation with revenues recycled lump-sum, cap and trade causes a reduction of 0.1% in aggregate employment in 2020. In contrast, under 100% auctioning with revenues devoted to marginal income tax cuts, there is a slightly positive (0.1%) impact on aggregate employment.

[40] The authors make two main arguments to support the claim that a larger percentage is needed. One is that free allocation must take place over a relatively short period of time, and yet compensate for potential profit losses over an infinite time horizon. Clearly the shorter the time-interval for free allocation relative to the interval over which losses are calculated, the larger the required free allocation. To us it seems most informative to use the same interval of time for profit calculations and the free allocation of allowances: that is, to consider the profit losses of some given interval of time, and then to determine how much free allocation, within that same time interval, is needed to prevent those profit losses. A second argument is that more free allocation is needed once one accounts for the heterogeneity of producers within industries. Consider the case where the cap-and-trade program would increase the profits of some firms within an industry that, on average, suffers a profit loss from the policy. In this case the average loss to the "losing" firms exceeds the average loss for the industry as a whole. Hence greater compensation would indeed be needed than what the industry-average profit loss suggests. Thus, in our analysis, to the extent that some of the firms in a losing industry experience profit increases as a result of cap and trade, our results understate the amount of free allocation needed to compensate the losing firms. However, it is hard to imagine that this issue has much empirical significance. The claimed bias requires that some of the firms in a losing industry actually experience profit increases from cap and trade. Within any of the eight most vulnerable industries we consider, one might expect some heterogeneity across firms in the magnitude of profit losses under 100% auctioning. But it seems highly doubtful that many or indeed any firms within those industries would enjoy increased profits as a result of the cap-and-trade program.

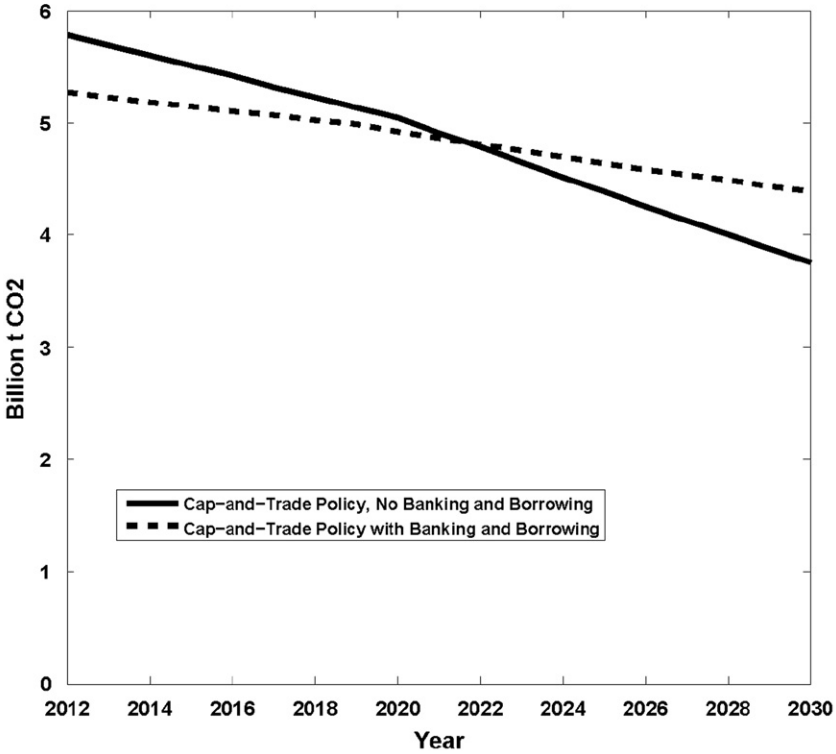

**Fig. 3.** Economy-wide $CO_2$ emissions with and without banking/borrowing 2012–2030.

*5.4.1. Including allowance banking and borrowing*

Several analysts emphasize that cost-effectiveness can be enhanced further through provisions for intertemporal trading of allowances – or allowance banking and borrowing.[41] Allowance trading helps promote equality of marginal abatement costs across various sources at given points in time. This helps lower policy costs. We modify the original cap-and-trade program to allow for allowance banking and borrowing over the interval 2012–2030. We require firms to have a zero bank balance (that is, use up all banked allowances or redeem all borrowed ones) by 2030.[42]

Fig. 3 displays the time-path of emissions in the absence and presence of banking-borrowing provisions.[43] This path is flatter under banking and borrowing: emissions fall short of annual caps in the short term, and exceed annual caps later on. Fig. 4 compares the paths of allowance prices in the central and banking/borrowing scenarios (as well as other scenarios to be described below). In the central case, the marginal abatement costs (and allowance prices) rise considerably faster than the rate of interest. This fast-rising price trajectory stems from the relatively steep decline in the time-profile for the aggregate emissions caps employed in this study (which is the time-profile under HR 2454). Under these conditions, firms have incentives to bank allowances and thereby avoid the especially high future abatement costs: they undertake extra emissions reductions in the near term (thus, bringing aggregate emissions below the short-term caps) and carry out fewer reductions in the future (thus causing aggregate emissions to exceed the longer-term caps). These adjustments imply a significantly flatter time-profile for emissions allowance prices compared with the central case (see Fig. 4). The differences in prices in the post-2020 period are especially dramatic.

Table 5 presents the impacts of alternative allocation methods in the presence and absence of the banking provisions. The lower abatement costs afforded by these provisions are reflected in lower GDP costs. Similarly, in many industries the losses of profit under 100% auctioning are smaller. Correspondingly, in most industries the required *value* of allowances needed to preserve profits is smaller, as indicated in Fig. 5a. At the same time, providing for banking has a relatively small impact on the numbers of allowances needed to prevent profit losses (Table 5 and Fig. 5b). This reflects two offsetting

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[41] See, for example, Kling and Rubin [21] and Leiby and Rubin [22].

[42] In equilibrium, in the presence of banking and borrowing, discounted marginal abatement costs (and thus allowance prices) will be equated across time. Hence allowance prices rise at the rate of interest. We model intertemporal banking by identifying the unique time-profile of allowance prices that meets two conditions: (1) allowance prices rise at the rate of interest, and (2) cumulative emissions over the period 2012 – 2030 (a function of the height of the time-path) match the cumulative emissions allowed by the yearly aggregate caps over this time interval. The latter condition assures that firms bring their bank balances to zero by 2030.

[43] The figure shows results under 100% auctioning of allowances, with revenues devoted to cuts in marginal income tax rates. In fact the emissions impacts under banking and borrowing are very similar under other allocation methods or other uses of policy revenues.

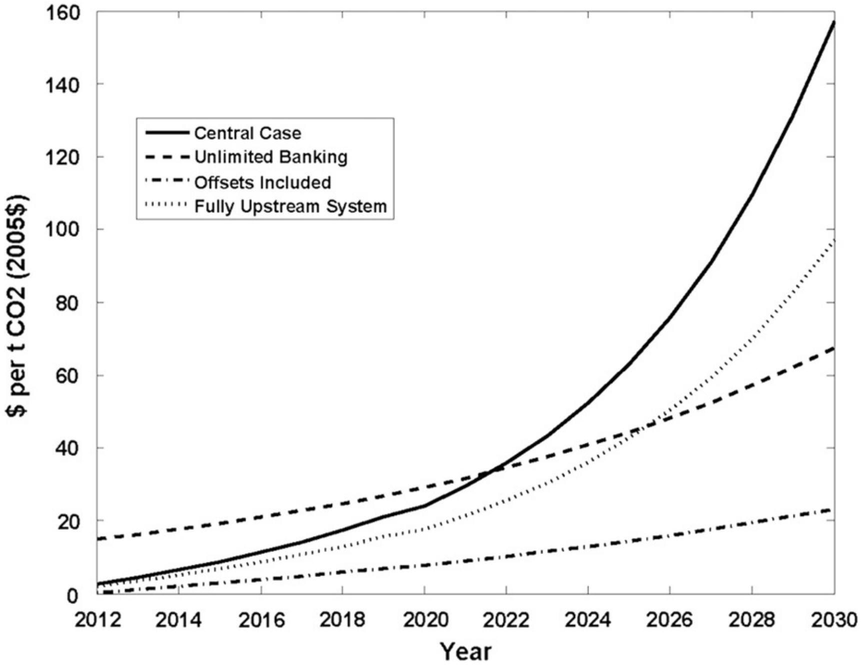

**Fig. 4.** Allowance prices under alternative policy designs, 2012–2030.

effects. On the one hand, the banking provisions imply lower abatement costs which, in the absence of changes in allowance prices, would imply that fewer allowances are needed to preserve profits. On the other hand, these provisions lead to a lower present value of abatement costs and allowance prices,[44] which means that to generate a given value of allowances (or compensation), more allowances must be offered. Because of these offsetting effects, the quantities of allowances needed to maintain profits (the numbers in parentheses in Table 5) do not change much when firms are given opportunities to bank allowances.

### 5.4.2. *Incorporating offsets*

Here we consider the profit impacts when points of regulation are allowed to substitute carbon offsets for an equal number of allowances. By purchasing offsets, firms can avoid high emissions abatement costs.[45] Domestic firms included among the points of regulation will choose to purchase offsets up to the point where the price of the marginal offset equals the marginal abatement cost. In equilibrium, the prices of allowances and offsets are equal.

For this exploration we introduce a domestic and foreign offset supply function. There is great uncertainty as to the costs of offset supply. Our domestic offset supply curve is based on U.S. EPA [23] estimates of potential greenhouse gas abatement in U.S. agriculture and forestry under alternative carbon price regimes. We assume that the supply curve for international offsets is the same as that for domestic offsets, and that the supply curve is fixed over time.[46] In our offset supply function, the yearly quantity supplied is 805 million tons at a real (2005$) price of price of $10, 1124 million tons at $15, and 1384 million tons at $20.

Table 5 also displays the impacts of alternative allocation approaches in the presence of offsets. As expected, under 100% auctioning the profit losses are considerably smaller than in the central case. The average percentage loss of profit for the eight most vulnerable industries is about 1.7%, as compared with 5% in the central case. Including offsets also reduces GDP costs considerably. In keeping with the smaller losses of profit, the *value* of allowances needed to prevent these profit losses is considerably lower when offsets are allowed, as shown in Fig. 5a. However, as indicated in Fig. 5b and Table 5, the *number* of allowances that must be freely allocated to preserve profits is higher in this case. The reason is that offsets substantially reduce allowance prices (see Fig. 4). Hence more allowances are needed to provide a given value of compensation.

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[44] As seen from Fig. 4, allowance prices are higher in the short term but lower in the longer term. The present value of these prices is lower than in the central case, in keeping with the fact that banking reduces the present value of abatement costs.

[45] Offsets are controversial because of the difficulties of determining "additionality," that is, ascertaining whether the emissions reducing or carbon-sequestering activities financed by offset purchases would not have taken place in the absence of such financing.

[46] Clearly this is a crude approach, but it is partly necessitated by the large uncertainties about international offset supply, where economic, administrative, and political factors are both significant and hard to predict.

**Table 5**

Profit and GDP impacts under alternative policy designs.[a]

| **Industry** | **Central case** | | | **Banking and borrowing allowed** | | | **Fully upstream implementation** | | | **Offsets allowed** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **100% auctioning** | **Profit-preserving free allocation** | **100% free allocation** | **100% auctioning** | **Profit-preserving free allocation** | **100% free allocation** | **100% auctioning** | **Profit-preserving free allocation** | **100% free allocation** | **100% auctioning** | **Profit-preserving free allocation** | **100% Free allocation** |
| **Percentage change in profits[b]** | | | | | | | | | | | | |
| Coal mining | −28.7 | 0 (3.2) | 178.8 | −31.7 | 0 (3.9) | 185.8 | −32.2 | 0 (4.4) | 187.1 | −13.8 | 0 (6.7) | 54.5 |
| Coal-fired electricity generation | −28.4 | 0 (3.2) | 177.2 | −27.7 | 0 (3.5) | 162.2 | −23.3 | 0 (3.3) | 135.6 | −9.9 | 0 (5.0) | 39.2 |
| Petroleum refining | −4.7 | 0 (0.7) | 29.4 | −4.0 | 0 (0.6) | 23.5 | −3.2 | 0 (0.5) | 18.8 | −1.1 | 0 (0.6) | 4.2 |
| Chemicals | −3.2 | 0 (2.4) | 20.7 | −2.8 | 0 (2.3) | 16.5 | −2.3 | 0 (2.1) | 13.5 | −0.7 | 0 (2.3) | 2.8 |
| Primary metals | −3.5 | 0 (0.8) | 22.2 | −3.3 | 0 (0.8) | 19.2 | −2.8 | 0 (0.8) | 16.8 | −1.0 | 0 (1.0) | 4.1 |
| Railroads | −2.5 | 0 (0.6) | 15.6 | −2.6 | 0 (0.7) | 15.3 | −2.3 | 0 (0.7) | 12.9 | −0.9 | 0 (1.0) | 3.5 |
| Electric transmission/ generation | −2.5 | 0 (2.5) | 15.5 | −2.3 | 0 (2.5) | 13.7 | −1.9 | 0 (2.4) | 11.5 | −0.7 | 0 (3.3) | 3.0 |
| Natural gas distribution | −2.8 | 0 (0.3) | 17.5 | −2.5 | 0 (0.3) | 14.5 | −2.1 | 0 (0.3) | 12.9 | −0.6 | 0 (0.4) | 2.7 |
| All industries above | −5.0 | 0 (13.7) | 31.6 | −4.9 | 0 (14.7) | 28.7 | −4.3 | 0 (14.5) | 25.3 | −1.7 | 0 (20.2) | 6.7 |
| All other industries | 0.1 | 0.2 | 0.4 | 0.1 | 0.2 | 0.4 | 0.0 | 0.1 | 0.3 | 0.1 | 0.2 | 0.2 |
| All industries | −0.2 | 0.2 | 2.7 | −0.2 | 0.2 | 2.5 | −0.3 | 0.1 | 2.1 | 0.0 | 0.1 | 0.7 |
| **GDP cost[c]** | 0.47 | 0.52 | 0.79 | 0.43 | 0.48 | 0.74 | 0.43 | 0.47 | 0.68 | 0.12 | 0.13 | 0.19 |

[a] In each policy experiment, revenues are recycled through marginal tax rate adjustments.

[b] Percentage change in the present value of profits over the interval 2009–2030. In the columns labeled ''Profit-Preserving Free Allocation'' the numbers in parentheses indicate, for each of eight industries, the percentage of economy-wide allowances that need to be freely allocated to preserve profits.

[c] Percentage change in the present value of GDP over the interval 2009–2030.

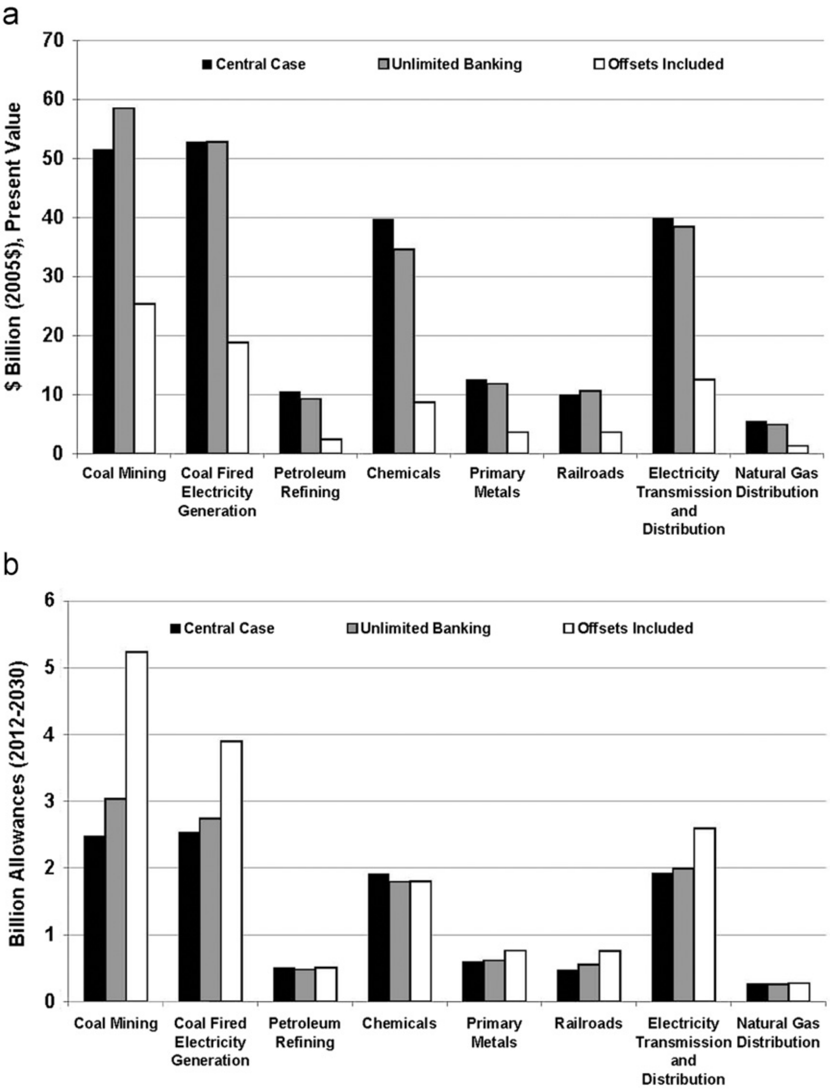

**Fig. 5.** Value and number of allowances necessary to preserve present value of after-tax profits under alternative policy designs: (a) present value (2012–2030) of freely allocated allowances and (b) total quantity (2012–2030) of freely allocated allowances.

### *5.4.3. A fully upstream program*

Here we consider a fully upstream system: the points of regulation are the mine mouth for coal, the wellhead for oil and natural gas, and the port of entry for imports of these fuels.[47] For comparability, here we apply the same time-profile for the aggregate emissions cap as in the central case. In addition, we designate the same industries as potential recipients of free allowances.

As shown in Table 5, under 100% auctioning the profit impacts tend to be slightly smaller in this case than in our central case. For the eight most vulnerable industries, the average profit loss is 4.3%, as compared with 5% in the central case. The difference reflects the fact a fully upstream system allows for somewhat more comprehensive coverage than the modified upstream system. It implies higher prices of carbon-based fuels for all industries rather than only for the principal carbon-using industries listed in Section 5.2.

GDP costs are also smaller in the fully upstream case. This too reflects the fact that abatement costs are spread more widely, so that an individual firm takes on a smaller share of the total effort required to meet the aggregate abatement target.

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[47] For a discussion of administrative and efficiency issues relevant to the choice between fully upstream, modified upstream, and downstream cap-and-trade systems, see Stavins [24].

### 5.5. Further sensitivity analysis

Table 6 indicates how changes in key parameters affect results under the central case scenario. Panels B and C examine the implications of more and less stringent time-profiles for the aggregate emissions cap. Here we increase or decrease in each year the required emissions reductions relative to the central case reductions for that year. More stringent caps imply larger losses of profit. However, they also imply higher allowance prices and reduce the number of allowances needed to prevent a profit loss, as can be seen from Figs. 6a and b. More stringent caps also raise GDP costs.

Panels D and E reveal the significance of alternative values for the elasticity of demand for energy. The high-elasticity case involves a doubling in each industry of the elasticities of substitution between the energy composite *E* and the materials composite *M*, as well as the elasticity of substitution between different forms of energy. The low-elasticity case reduces each of these elasticities by 25% in each industry. Higher elasticities are a boon for carbon users but a bane for carbon suppliers: they imply that more of the policy burden can be shifted from users to suppliers. The industries in

**Table 6**

Sensitivity analysis[a]: change in profits, value of allowances required for compensation, and GDP cost

| | Coal mining | Coal-fired electricity generation | Petroleum refining | Chemicals | Primary metals | Railroads | Electric transmission and distribution | Natural gas distribution | Total[b] | GDP cost[c] |
|---|---|---|---|---|---|---|---|---|---|---|
| **A. Central case** | | | | | | | | | | |
| 100% auctioning[d] | −28.7 | −28.4 | −4.7 | −3.2 | −3.5 | −2.5 | −2.5 | −2.8 | −5.0 | 0.47 |
| 100% Free allocation | 178.8 | 177.2 | 29.4 | 20.7 | 22.2 | 15.6 | 15.5 | 17.5 | 31.6 | 0.79 |
| Value of allowances needed to preserve profits[e] | 54.1 | 55.5 | 11.1 | 41.7 | 13.2 | 10.5 | 41.9 | 5.9 | 233.9 | n.a. |
| **B. More stringent caps** | | | | | | | | | | |
| 100% auctioning | −32.4 | −35.0 | −7.0 | −4.8 | −4.6 | −2.9 | −3.2 | −3.9 | −6.4 | 0.70 |
| 100% Free allocation | 229.3 | 247.6 | 50.0 | 34.2 | 33.4 | 21.4 | 23.1 | 29.1 | 46.2 | 1.13 |
| Value of allowances needed to preserve profit | 60.0 | 67.0 | 16.4 | 59.8 | 17.1 | 12.3 | 54.0 | 8.4 | 295.1 | n.a. |
| **C. Less stringent caps** | | | | | | | | | | |
| 100% Auctioning | −24.3 | −21.4 | −3.0 | −2.2 | −2.6 | −2.0 | −1.9 | −2.0 | −3.8 | 0.31 |
| 100% Free allocation | 134.0 | 117.7 | 17.0 | 12.1 | 14.7 | 11.6 | 10.7 | 11.9 | 21.3 | 0.54 |
| Value of allowances needed to preserve profit | 46.4 | 42.1 | 7.3 | 27.9 | 9.9 | 8.9 | 33.0 | 4.5 | 180.2 | n.a. |
| **D. Lower demand elasticities** | | | | | | | | | | |
| 100% Auctioning | −30.9 | −31.5 | −7.0 | −5.6 | −5.3 | −3.8 | −1.1 | −3.6 | −5.8 | 0.81 |
| 100% Free allocation | 297.4 | 303.6 | 67.1 | 53.8 | 51.2 | 37.0 | 9.8 | 34.3 | 55.1 | 1.27 |
| Value of allowances needed to preserve profit | 56.4 | 57.1 | 16.7 | 69.0 | 19.5 | 15.6 | 15.8 | 7.5 | 257.8 | n.a. |
| **E. Higher demand elasticities** | | | | | | | | | | |
| 100% Auctioning | −20.3 | −16.0 | −1.9 | −0.8 | −1.3 | −0.6 | −1.2 | −1.4 | −2.5 | 0.15 |
| 100% Free allocation | 60.8 | 47.7 | 5.8 | 2.4 | 3.9 | 2.0 | 3.6 | 4.3 | 7.6 | 0.24 |
| Value of allowances needed to preserve profit | 38.3 | 31.5 | 3.6 | 9.2 | 4.5 | 2.7 | 20.0 | 2.5 | 112.2 | n.a. |
| **F. Higher adjustment costs** | | | | | | | | | | |
| 100% Auctioning | −27.8 | −26.3 | −4.7 | −3.3 | −3.5 | −2.5 | −1.2 | −2.7 | −4.3 | 0.47 |
| 100% Free allocation | 194.0 | 183.6 | 33.0 | 22.8 | 24.2 | 17.5 | 8.5 | 18.0 | 30.3 | 0.72 |
| Value of allowances needed to preserve profit | 55.1 | 53.3 | 11.9 | 43.7 | 13.8 | 12.1 | 22.1 | 6.7 | 218.7 | n.a. |
| **G. Lower adjustment costs** | | | | | | | | | | |
| 100% Auctioning | −28.7 | −29.4 | −4.6 | −3.2 | −3.5 | −2.6 | −1.2 | −2.9 | −4.6 | 0.46 |
| 100% Free allocation | 197.2 | 201.8 | 31.2 | 21.9 | 24.1 | 17.8 | 8.2 | 19.5 | 31.5 | 0.77 |
| Value of allowances needed to preserve profit | 53.3 | 56.2 | 10.6 | 39.7 | 12.8 | 10.5 | 19.1 | 5.7 | 207.7 | n.a. |

[a] In each policy experiment, revenues are recycled through marginal tax rate adjustments.

[b] Percentage change in total profits for all industries reported in this table.

[c] Percentage change in the present value of GDP over the interval 2009–2030.

[d] Percentage change in the present value of profits over the interval 2009–2030.

[e] Present value ($ Billion 2005$) of allowances freely allocated over the interval 2012–2030.

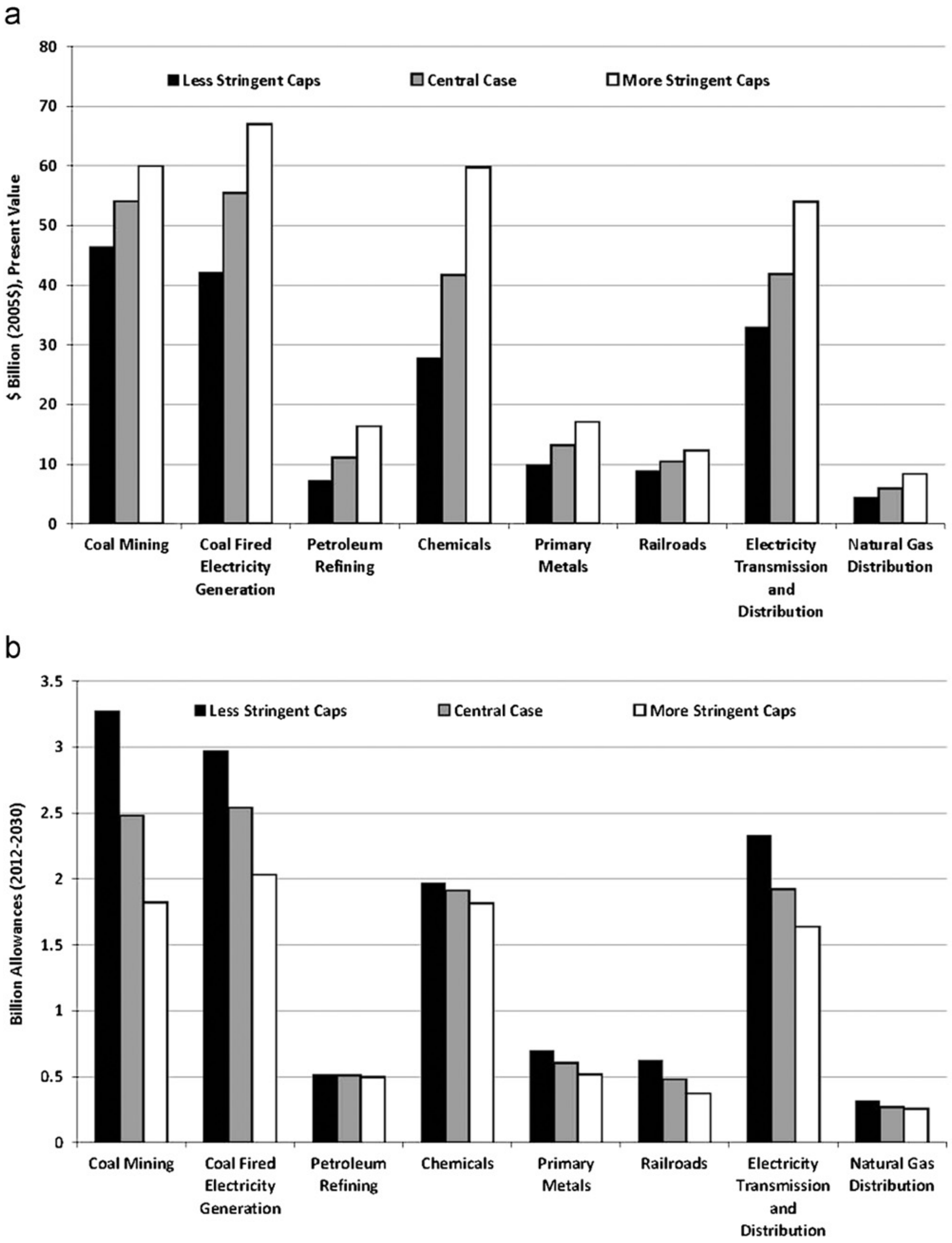

**Fig. 6.** Sensitivity analysis: value and number of allowances to preserve present value of after-tax profits under more and less stringent caps: (a) present value (2012–2030) of freely allocated allowances and (b) total quantity (2012–2030) of freely allocated allowances.

Table 6 are both users and suppliers. We find that the former impact tends to dominate, as higher elasticities are associated with smaller losses of profit.[48]

Panels F and G consider alternative assumptions for the elasticity of supply. We regulate this elasticity by altering the parameter $\xi$ in the adjustment cost function (Eq. (4) above) in all industries. Changes in adjustment costs have differing effects depending on where a given firm lies in the carbon supply chain. Upstream primary suppliers of carbon tend to benefit from lower adjustment costs, since they are able to shift downstream a larger share of the cost-increases from cap and trade. Firms that are further downstream in the carbon supply chain tend to fare less well when adjustment costs for all industries are lowered: although they are able to shift more of their own costs, they inherit greater costs that are shifted

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[48] However, for the coal mining and coal-fired electricity generation industries, higher elasticities are associated with larger requirements for free allowances. Allowance prices are lower in the high-elasticity case, which implies that more allowances are needed to yield a given value of compensation.

to them from more upstream firms. In Table 6 we find that the varying industry impacts of changes in adjustment costs tend to cancel out, so that the overall GDP costs are not much affected.

In nearly all cases considered in Table 6, the total allowances required to preserve profits in the most vulnerable industries is below 15%. The total never exceeds 25%.

## 6. Conclusions

This study applies a numerical general equilibrium model to assess the impacts of alternative cap-and-trade policies on profits of U.S. industries and the overall economy. The model's close attention to the dynamics of physical capital makes it especially well-suited to evaluate the profit impacts.

We find that freely allocating a relatively small fraction of the emissions allowances generally suffices to prevent profit losses among the eight industries that, without free allowances or other compensation, would suffer the largest percentage losses of profit. Under a wide range of cap-and-trade designs, freely allocating less than 15% of the total allowances prevents profit losses to these most vulnerable industries. Allocating 100% of the allowances substantially overcompensates these industries, in many cases causing more than a doubling of profits.

When just enough free allocation is offered to compensate (but not overly compensate) the most vulnerable industries, considerable auction revenue is generated, yielding significant opportunities to avoid distortionary taxation and lower policy costs. In our simulations, when auction revenues are used to finance cuts in marginal income tax rates, the resulting GDP costs are about one third lower than in the case where all allowances are freely allocated and no auction revenue is generated. In contrast, when auction revenues fund lump-sum rebates, there are no cost savings relative to the case of 100% free allocation.

The finding that profit-preservation requires a small percentage of free allowances is robust, emerging under policy designs that differ according to the presence or absence of provisions for offsets. It also applies across policies differing in stringency. When the overall cap is tighter, firms need to receive free a higher *value* of allowances to maintain profits. However, greater stringency also leads to higher allowance prices (the value of each allowance is greater). Hence the number of free allowances that firms require to attain needed allowance value does not change much with the stringency of cap-and-trade policy.

It should be recognized that the simulation experiments in this paper consider only a subset of the provisions contained in recent federal cap-and-trade proposals. In particular, they do not incorporate border-tax adjustments or other forms of industry assistance not achieved through free allowance allocation. These provisions clearly can influence the profit impacts and economy-wide costs of cap and trade.

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