DISCUSSION PAPER

Output-Based Allocations of Emissions Permits

Efficiency and Distributional Effects in a General Equilibrium Setting with Taxes and Trade

Carolyn Fischer and Alan Fox

RESOURCES
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Output-Based Allocations of Emissions Permits:
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Abstract

The choice of mechanism for allocating tradable emissions permits has important efficiency and distributional effects when tax and trade distortions are considered. We present different rules for allocating carbon allowances within sectors (lump-sum grandfathering, output-based allocation [OBA], and auctioning) and among sectors (historical emissions and value-added shares). Using a partial equilibrium model, we explore how OBA mitigates price increases, limits incentives for conservation in favor of lowering energy intensity, and changes relative output prices among sectors. We then use a computable general equilibrium model from the Global Trade Analysis Project, modified to incorporate a labor/leisure choice, to compare overall mechanism performance. The output subsidies implicit in OBA mitigate tax interactions, which can lead to higher welfare than grandfathering. OBA with sectoral distributions based on value added generates effective subsidies similar to a broad-based tax reduction, performing nearly like auctioning with revenue recycling, which generates the highest welfare. OBA based on historical emissions supports the output of more polluting industries, which more effectively counteracts carbon leakage but is more costly in welfare terms. Industry production and trade impacts among sectors that are less energy intensive are also quite sensitive to allocation rules.

Key Words: emissions trading, output-based allocation, tax interaction, carbon leakage

JEL Classification Numbers: Q2, Q43, H2, D61

Contents

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Carolyn Fischer and Alan Fox*

Introduction

Increasingly in recent years, many countries have been incorporating economic instruments into environmental policy, particularly "cap-and-trade" policies that fix emissions limits and allow firms to trade the rights to emit up to that cap. The United States is expanding its use of marketable emissions permits from sulfur dioxide (SO_2) to nitrogen oxides (NO_x) and potentially mercury, and proposals to reduce CO_2 include emissions trading. The European Union is proceeding with the design of an emissions trading system for controlling greenhouse gases. Other countries, including Canada, are considering an emissions trading program for greenhouse gases.

When emissions are capped, they become a scarce and valuable resource. An important political—and economic—question is how to allocate these pollution rents. Most economists, citing the large literature on the "double dividend," recommend that permits be auctioned so that the revenues can be used to lower other distortionary taxes in the economy that otherwise increase the cost of environmental regulation. In practice, however, governments prefer to forgo the revenues and allocate the permits gratis to the industries covered by the trading system. For example, in its acid rain program, the United States distributed all of the SO_2 allowances, less a small reserve, to existing coal-fired power plants, an annual value in the range of $2 billion. The European Union has mandated that member states freely distribute their permits, imposing a maximum of 5% for auctioning permits in the first trading period (2005–2007). The McCain–Lieberman Climate Stewardship Act of 2003, the main proposal on the table to limit greenhouse gas emissions in the United States, provides for sector-based allocations but also some share (to

be specified) to go a special nonprofit corporation that would be established to benefit consumers, the Climate Change Credit Corporation (CCCC).

A common method for gratis allocation is "grandfathering," which gives participating firms a fixed number of allowances. In the absence of other market failures, this lump-sum allocation offers the same incentives as auctioning permits. However, in giving away all the permits, the value of the rents transferred to incumbent firms can vastly outweigh their actual cost burden from the regulation.[1] Any increase in marginal production costs tends to be passed on to consumers, who get no relief from the allocation. Another distributional concern is that firms that enter later may not get any allocation and have to purchase all their permits on the market. Thus, attention is turning toward allocation methods that can be updated (or will update themselves) according to changing market conditions and composition.

Accordingly, one method frequently advanced is output-based allocation (OBA). For example, a cap may be placed on the emissions of several sectors; each sector would be granted a fixed number of those permits, and within each sector, individual firms would receive permits proportional to their share of their industry's output. However, since output is a control variable of the firm, the allocation policy itself has behavioral effects, which in turn tend to reduce the efficiency of the environmental policy. Specifically, the allocation creates a subsidy to output, which limits incentives to reduce emissions through conservation and diverts attention toward lowering energy intensity.

Environmental policy, of course, does not operate in a vacuum. The efficiency of a standard Pigovian tax or an equivalent emissions permit system relies on the assumption that markets are not otherwise distorted. Where distortions exist, environmental policy may exacerbate them, rendering simple Pigovian policies suboptimal. We focus on two major examples that can justify support for output: imperfect participation and tax interaction.

Imperfect participation occurs when the environmental program exempts significant portions of an industry—for example, small producers, sectors in which monitoring is more difficult (like nonpoint sources), or sectors outside the jurisdiction of a regulator (like foreign producers of a global pollutant). In greenhouse gas policy, this issue is known as carbon leakage. Since they bear no environmental burden, excluded producers suddenly have relatively low costs compared with participants. Industry production then tends to shift away from participants

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[1] See Burtraw et al. (2002) and Bovenberg and Goulder (2000).

toward nonparticipants (who are still emitting costlessly). An output subsidy for participants would discourage such intra-industry shifting of production and emissions. Bernard et al. (2001) show that when the products of the exempt firms cannot be taxed to reflect the value of the embodied emissions, an output subsidy may be warranted—to the extent these products are close substitutes for those produced by regulated firms.

Taxing labor income creates another kind of imperfection by distorting the labor/leisure trade-off; in a sense, it taxes all consumption goods at the same rate, making them more expensive and making consuming leisure more attractive than consuming goods. Adding an environmental policy that makes some consumption goods even more expensive further distorts this trade-off. Environmental policies that raise revenues that can be used to lower distorting labor taxes unambiguously raise welfare from the no-policy scenario. However, the optimal environmental tax (or auctioned permit price) in this second-best setting is still less than the Pigovian tax.[2] Policies that do not raise revenue (such as grandfathered permits) must have positive environmental benefits that outweigh the increased deadweight loss from the labor tax on the margin.[3]

By providing a subsidy to output, output-based rebating may mitigate some of the impact of the tax interaction effect compared with lump-sum distribution. The implicit subsidy lowers the price of the dirty good, making goods consumption in general less expensive and real wages higher. However, the gain from a reduced disincentive must be balanced against the higher abatement cost of achieving the same level of emissions reduction. The net result may (or may not) be an improvement over distributed permits in this situation.

Parry et al. (1999) show that performance standards can generate fewer efficiency costs than distributed permits in this second-best system. In their model, performance standards are less costly the less abatement is to be done by output adjustment than by emissions rate adjustment. On the other hand, Jensen and Rasmussen (1998), using a general equilibrium model of the Danish economy, find that allocating emissions permits according to output dampens sectoral adjustment but imposes greater welfare costs than grandfathered permits. Dissou (2003),

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[2] This result is well established in the literature, for example, Bovenberg and van der Ploeg (1994), Bovenberg and de Mooij (1994), Bovenberg and Goulder (1996), Parry (1995), and Goulder (1995).

[3] See Parry (1996), Parry et al. (1999), and Goulder et al. (1997). Fullerton and Metcalf (2001) make the distinction that policies that create scarcity rents (as opposed to policies that raise no revenue) are those that interact with labor tax distortions.

in an application to greenhouse gas reductions in Canada, finds that performance standards can mitigate losses in gross domestic product, but welfare is lower relative to grandfathered permits.

Although performance standards bear similarities to output-based allocation, there are some important differences. Performance standards (particularly tradable ones) allocate permits according to output and the target emissions intensity. In theory, they could be set so as to equate marginal abatement costs across multiple sectors.[4] Such a result can be replicated with a multisector cap-and-trade system with OBA, but with a single set of allocations at the sector level. In practice, many different sectoral allocation rules are possible—and more plausible—than expected equilibrium average emissions. Since these sectoral allocations determine the relative subsidy for output, we closely examine the effects of different rules for dividing an emissions cap among sectors.

We look at how well OBA can address these issues relative to grandfathering or auctioning emissions permits. We begin with some theoretical background, using a partial-equilibrium analytical model, before proceeding to the general-equilibrium numerical analysis. We use a version of the computable general equilibrium (CGE) model GTAP-EG, modified to incorporate a labor/leisure choice, to look at how well OBA can address issues of equity and efficiency relative to grandfathering emissions permits or auctioning with revenue recycling and with trade effects.

We find that the rules for setting the initial sectoral caps play an important role in determining the changes in welfare, industrial production, employment, and trade induced by the emissions policy. OBA with sectoral distributions based on value added generates effective subsidies more like a broad-based tax reduction, performing nearly like auctions and clearly outperforming lump-sum allocations. OBA based on historical emissions supports the output of more polluting industries, which more effectively counteracts carbon leakage but is more costly in welfare terms. With less contraction among polluting sectors, more reductions must be sought among less carbon-intensive sectors, signaled by a higher carbon permit price. However, because of the importance of the tax interaction problem, historical OBA remains less costly in net welfare terms than traditional permit grandfathering. In all cases output-based rebating is strictly less efficient than auctioned permits, which raise revenues that offset labor taxes and encourage

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[4] This is the method of Dissou (2003) and Goulder et al. (1999).

more work, and they achieve this in a manner that does not distort the relative prices of dirty and clean goods.

Partial Equilibrium Model

To build intuition for the first-order effects of different allocation mechanisms, we first present a partial equilibrium model of the affected industry. In the next section, we incorporate these industry incentives into a general equilibrium setting, to better account for the incidence of allocation on all prices and interactions with the broader tax system.

Consider a perfectly competitive industry with a representative firm that is a price taker in both product and emissions markets. The unit cost function, c, is represented as a decreasing convex function of the emissions rate μ. In other words, the firm chooses a technological or input mix that implies a given emissions rate and exhibits constant returns to scale, which corresponds to a constant per-unit cost. Let y be the output of our representative firm, p the market price for the good produced, and t the price of a pollution permit. Consumer inverse demand $p(y)$ is downward sloping and, in equilibrium, equal to the market price.

Lump-Sum Allocation

With lump-sum allocation, such as grandfathering or auctioned permits, the allocation is invariant to firm behavior. When permits are grandfathered, we assume that this allocation is unconditional and is unaffected by decisions to enter or exit the market. Consequently, the choices of emissions rate and output are unaffected by the allocation, at least in a partial equilibrium model.

Let A be the lump-sum allocation to the firm. Firm profits are

$$\pi^{LS} = (p - c(\mu) - t\mu)y + tA \tag{1}$$

By the first-order conditions, the firm equalizes the marginal cost of emissions rate reduction with the price of emissions

$$-c'(\mu) = t \tag{2}$$

and the market price reflects the unit cost of production and the external cost of the embodied emissions:

$$p = c(\mu) + t\mu \tag{3}$$

This result corresponds to standard Pigovian pricing. If each sector's emissions cap were initially set to generate socially optimal reductions, in a market with multiple sectors, trade

across sectors would reproduce the same efficient emissions and product pricing—excluding other market failures and general equilibrium effects.

Output-Based Allocation

With output-based allocation, the industry receives an allocation *A,* which is then distributed among the firms in proportion to their output. In equilibrium, the per-unit allocation is $a = A / y$, which a representative competitive firm takes as given. Although we present this representation as a result of an allocation rule with updating in the short run, this implicit subsidy can also represent the long run effects of grandfathered permits that are conditional on continued operation.[5] The profit function for a representative firm within an industry is expressed as

$$\pi^{OBA} = (p - c(\mu) - t(\mu - a)) y \qquad (4)$$

The firm's profits are therefore reduced by the cost of the additional permits it must purchase (if $\mu > a$) or increased by the value of excess permits it can sell off (if $\mu < a$). To optimize profits, the firm equalizes the marginal cost of emissions rate reduction as in (2). However, given any emissions rate, the market price is lower than with lump-sum allocation by the value of the per-unit allocation:

$$P = c(\mu) + t(\mu - a) \qquad (5)$$

Consequently, output will be higher. In other words, with output-based allocation, the Pigovian emissions rate and price will lead to greater than optimal emissions. The dual to this problem is that to achieve the same level of emissions as the optimal case, the marginal price of emissions must rise and the emissions rate must fall. Thus, for a given amount of emissions reduction, output-based rebating raises the marginal cost of emissions reduction relative to efficient policy.

We also note that a lump-sum allocation that is conditional on operating (not exiting the market) can offer long-run incentives that are similar to output-based allocation, since the long-run average cost is lowered by the per-unit value of the allocation.

Next, consider two types of permit markets in which this industry might operate. In a restricted market, the industry has its own emissions target. In a broad-based market, it participates in a larger cap-and-trade system with other industries, each of which has its own

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[5] In other words, if the firm loses the permits if it exits the industry, the allocation becomes an operation subsidy that lowers long-run average costs by *tA/y* per unit. See Boehringer et al. (2002).

allocation mechanism. An important point is that the subsidy is a function of not the industry average emissions rate but the average allocation. In a restricted market, the average emissions rate will equilibrate to equal the average allocation; in a broad-based market, it need not.

Restricted Permit Markets

In restricted permit markets, all the firms participating in a given permit market compete in a single allocation pool. These firms remain price takers both in product and in permit markets. Total emissions for the restricted market are fixed at the Pigovian level of overall emissions (i.e., for sector i, $\overline{E}_i = \mu_i^* y_i^*$ where μ_i^* and y_i^* satisfy (2) and (3) with $t = MB$). Permits totaling $\overline{E}_i$ are allocated among program participants in each sector according to output shares. The rebate to individual firms in sector i thus equals $a_i = \overline{E}_i / y_i$ per unit of output.
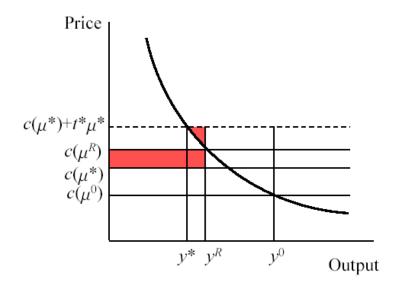
Let us denote this equilibrium with superscript *R*. In this case, the average permit allocation equals average emissions in each self-contained permit program, and $a_i^R = \mu_i^R$. Given that $y_i^R > y_i^*$, because of the presence of the output subsidy, to achieve the required emissions level, average emissions rates will have to be lower: $\mu_i^R > \mu_i^*$. As a result, permit prices will be higher, reflecting the higher marginal cost of control: $t_i^R = -c'(\mu_i^R) > -c'(\mu_i^*)$.

Figure 1 depicts the excess burden of output-allocated permits compared with the social optimum in this partial equilibrium setting. The dead-weight loss occurs in two parts: (a) higher-than-optimal production costs and (b) the damages implied by emissions from the excess production, less the corresponding consumer surplus. In other words, even though total emissions levels are optimal, marginal damages from output still exceed the marginal benefits.

It is worth noting that applying separate cap-and-trade programs with output-based allocations to multiple sectors is equivalent to setting performance standards. When the sectoral allocation is based on Pigovian emissions, as in the case presented here, then marginal abatement costs will diverge according to the elasticity of demand for each sector's output. Alternatively, one could set the performance standards such that marginal abatement costs would be equalized; to replicate this method with OBA requires allocating more permits (compared with the Pigovian levels) to sectors with relatively more elastic demand. Dissou (2003) simulates this method, using a CGE model to assess the effects of performance standards, set for each sector to both equalize marginal abatement costs and achieve an overall emissions target. A similar method was used by Goulder et al. (1997). Effectively, this represents OBA with a different rule for allocating permits at the sectoral level.

Figure 1: Partial Equilibrium Efficiency Loss from OBA

Consequently, modeling performance standards to equalize marginal abatement costs does not represent OBA more generally, since the rule for determining the overall sector's allocation can vary, and it is important. Furthermore, with multiple sectors, it is a far more complicated policy problem to set performance standards so as to equalize marginal abatement costs, whereas markets achieve that with a multisector trading program with OBA.

Multisector Permit Markets

Of course, many pollutants—including greenhouse gases—are emitted from a variety of activities and rarely just a single sector. In this case, allowing permit trading across sectors in a broad-based market can allow for a more efficient allocation of effort. However, output-based allocation of permits can also affect the distribution of effort.

By the same logic as the restricted market model, equilibrium permit prices in the broad market must be higher than optimal, since the output subsidies limit conservation incentives, requiring more emissions rate reduction and higher marginal costs of emissions control. If the sectors are not identical—that is, if they display different cost structures, emissions, or demand elasticities—then the implicit subsidies and their effects will vary. In restricted markets with OBA, sectors with greater demand elasticities will compensate by driving up marginal abatement costs more.

In other words, suppose each sector's targets under restricted permit markets were set so that marginal abatement costs would be equalized with lump-sum allocation; those costs diverge

with OBA. With trade, marginal abatement costs are again equalized across sectors; the sectors with relatively inelastic demand will tend to increase their overcompliance and sell permits to those whose consumers would otherwise more easily conserve or find substitutes. Furthermore, as costs and thereby output change with multisector trade, the average allocation will not necessarily reflect average emissions in each sector.

To understand the intuition behind these results, consider this simple but extreme example. Two sectors compete in a single permit market, each with output-based allocation of permits within the sector, but one sector has perfectly inelastic demand. Let Sector 1 be that sector; its total allocation equals $A_1 = \mu_1^* y_1^*$, and since the equilibrium output level does not change, its average allocation always equals $a_1 = \mu_1^*$. In an equilibrium with multisector emissions trading (denoted with superscript M), Sector 1 then has an output price of $p_1^M = c(\mu_1^M) + t^M(\mu_1^M - \mu_1^*)$. Meanwhile, Sector 2 faces more elastic demand. It receives a total allocation of $A_2 = \mu_2^* y_2^*$, which will correspond to an average allocation of $a_2^M = \mu_2^* y_2^* / y_2^M$. The price in that sector then equals $p_2^M = c(\mu_2^M) + t^M(\mu_2^M - \mu_2^* y_2^* / y_2^M)$. In a permit market equilibrium, we know that total emissions across sectors must equal the total cap: $\mu_1^M y_1^* + \mu_2^M y_2^M = A_1 + A_2$. Furthermore, the marginal costs of reducing emissions rates per unit of output must be equalized at the permit price: $-c'(\mu_1^M) = -c'(\mu_2^M)$.

Suppose the emissions price were equal to the optimal marginal abatement cost; whereas Sector 1 always supplies the optimal quantity, in Sector 2, with the output allocation subsidy, a greater quantity will be demanded. The emissions embodied in the extra output would violate the cap, so permit prices must rise and emissions rates fall in both industries to maintain the cap. Overall, Sector 1 will emit less than the socially optimal amount, and Sector 2 will emit more.

Alternatively, we can compare this equilibrium to that of restricted permit markets with OBA. With separate permit markets, consumers in the sector with inelastic demand reap the full benefit of the output subsidy, but efficiency is not affected. In Sector 2, efficiency losses are present, since the emissions rate and consumer price are lower than optimal. When these sectors are allowed to trade permits, the permit price would then equilibrate in between, with Sector 1 lowering emissions rates (being more than compensated by the subsidy transfer) and Sector 2 raising them (but still not as high as optimal emissions intensities), so that $\mu_1^M < \mu_1^*, \mu_2^R < \mu_2^M < \mu_2^*$. For Sector 2, lower permit prices and lower control costs mean that

consumer prices are even lower than in the restricted permit market case, even though the value of the allocation subsidy falls as well.[6] Consumer prices in Sector 1 must also be lower; according to the first-order condition for profit maximization, if a firm wants to decrease its emissions rate and trade, its overall costs must be lower.

Taken from another view, output-based allocations can create false gains from trade, based on the extent to which abatement choices are distorted by the output subsidy. Sectors with relatively inelastic demand functions realize a comparative advantage in abatement arising, in a sense, from their greater ability to pass costs along to consumers.

The net effects of permit trading on welfare depend on whether the efficiency loss decreases as it is redistributed. Overcompliance in Sector 1 represents a real resource cost, but it allows Sector 2 to reduce its overcompliance. However, its output price then reflects even less of the cost of the embodied emissions. As the costs of reducing emissions rates are presumably convex, cost savings will arise from spreading overcompliance across the sectors. Thus, the question in the partial equilibrium problem is whether those savings outweigh the additional efficiency loss from more overproduction in Sector 2.

In a general equilibrium framework, however, this output effect may be less costly because of interactions with tax distortions and uncovered sectors. To explore these trade-offs, we next apply this sectoral model of emissions regulation with output-based allocation to a general equilibrium model of the U.S. economy and the case of reducing CO_2.

General Equilibrium Model with Trade and Taxation

Description

Since we are primarily concerned with the distributional and efficiency effects of emissions permit allocation mechanisms with taxes and trade, we employ a CGE model from the Global Trade Analysis Project (GTAP), which offers richness in calculating trade impacts. In particular, we can look in detail at the effects on a more diverse and disaggregated set of energy-

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[6] See Fischer (2003).

using sectors than in most climate models.[7] However, this static model is not designed specifically to study climate policy. It lacks the capability to examine certain issues of import, particularly dynamic responses, since it does not project energy use into the future or allow for technological change. As such, our results should be considered illustrative of the near-term effects on different sectors of implementing a climate policy using different allocation mechanisms for emissions permits. Our impacts of interest include CO_2 emissions, production, trade, and employment by sector, as well as overall welfare, both in the United States and abroad, and carbon leakage.

The model and simulations in this paper are based on version 5 of the GTAPinGAMS package developed by Thomas Rutherford and documented for version 4 of the dataset and model in Rutherford and Paltsev (2000). The GTAP-EG model serves as the platform for the model outlined here. The GTAP-EG dataset is a GAMS dataset merging version 5 of the GTAP economic data with information on energy flows. A more complete discussion of the energy data used can be found in Complainville and van der Mensbrugghe (1998).

Three features are added to the GTAP-EG structure allow us to model the impact of the policy scenarios. First, we add a carbon price. Second, the appropriate structure for simulating an output-based allocation scheme must be incorporated into the model. Third, the household is given a labor/leisure choice so that labor taxes are distorting. This distortionary tax allows us to conduct simulations recycling revenue from pollution permits to offset the distorting tax instrument.

Incorporating Output-Based Allocation

Several changes need to be made to the GTAP-EG code to incorporate output-based allocation of pollution permits. The profit function is not directly accessible in the MPSGE framework. Instead, we incorporate output-based permit allocation through the production function as a sector-based subsidy, combining it with side constraints on the values of *a* to duplicate the effect on the profit function above. Additionally, we create an additional composite

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[7] We report impacts on 18 nonenergy sectors and 5 energy sectors. Most of the major climate models are much more highly aggregated, with five or fewer nonenergy sectors (Fischer and Morgenstern 2003). Some have more detail in modeling specific energy supplies. However, climate models based on GTAP, such as recent versions of ABARE-GTEM, can offer richness in all of these dimensions.

fossil fuel nest to production. This allows us to incorporate the pollution permit as a Leontief technology, allowing us to track pollution permits through the model.

In the original GTAP-EG model, the treatment of energy goods does not allow for tracking of permits by sector. To track pollution permits, we must ensure that one permit is demanded for each unit of carbon that enters into production. It is accomplished by separating the energy goods into a separate activity, a Leontief technology combining the polluting inputs with permits, creating a new composite good (labeled *ffi* in the code, for fossil fuel input). The composite of permit and energy input is then included in the production block for the output good (*y*), ensuring that the implicit cost of embodied emissions is reflected in the output price.

The next step is to incorporate the endogenous subsidy implied by the output-based allocation of permits within a sector. We mimic this in the form of an endogenous tax rate, *z*, into the sector's production function: $z_{i,r} = -t_r \dfrac{A_{i,r}}{y_{i,r}} / p_{i,r}$, where $A_{i,r}$ is the sector-level allocation for sector *i* of country *r*.

We consider two potential rules for determining this sector-level allocation. The historical emissions rule defines the sector's apportionment of pollution permits as the baseline unit demand for carbon multiplied by the percentage cap (κ_r) on emissions: $A_{i,r}^{Hist} = \kappa_r \sum_{fe} \chi_{fe,i,r} \phi_{fe,i,r}$. The variable $\chi_{fe,i,r}$ is the carbon coefficient for final energy good $fe \in \{coal, oil, gas\}$ in sector *i* of country *r*. The variable $\phi_{fe,i,r}$ represents the demand of the fossil fuel input. The value-added rule apportions the same number of permits based on each of the energy-using sector's share of value added in the base year: $A_{i,r}^{VA} = \sum_j A_{i,r}^{Hist} \dfrac{VA_{i,r}}{\sum_j VA_{j,r}}$.

The allocation mechanism is active only within those industries or sectors that demand carbon-containing fuel as an intermediate input. Within the GTAP-EG model, the following sectors are excluded: coal, petroleum and coal products, crude oil, natural gas, mining, and dwellings. Final demand for energy products is also subject to emissions permitting. The permits for these activities are freely traded in the same marketplace as those initially allocated on the basis of output. We have a system in which all pollution is subject to permitting and all permits are tradable within the country. The difference lies in how permits are distributed in the baseline and how revenues are recycled.

Incorporating Labor/Leisure Choice

The GTAP-EG model has also been extended by incorporating a labor/leisure choice into the household's decision. The procedure is documented in Fox (2002). Incorporating a labor/leisure choice allows us to treat the labor tax as a distorting tax, hence creating a distorting policy instrument to offset with auction permit revenues. Since we have no data on labor taxes within the GTAP-EG database, we assume a labor tax rate of 40% within Annex B countries and a 20% tax rate within all other countries.[8]

Policy Experiments

The Climate Stewardship Act proposes to cap emissions in 2010–2016 to 2000 levels, eliminating a decade of increase.[9] In this spirit, we set the basic policy goal to be a similar 14% reduction of CO_2 emissions from the base-year level (1997 in our case).[10] The Climate Stewardship Act also provides for sector-level apportionment to covered emissions sources,[11] with broad consideration given to historical emissions as well as shares to CCCC. Details— including the actual shares and the distribution methods within sectors to the firms—are left to future rulemakings by the Commerce Department secretary and the administrator of the Environmental Protection Agency. It is also unclear whether CCCC would use the revenues from permit sales to offer lump-sum rebates (dividends) to consumers, lower federal taxes, or otherwise target the funds. In other words, this overall framework—should it be enacted—seems to offer a wide range of possibilities for allocation; hence, it is important to understand the consequences of alternative mechanisms.

To concentrate on the effects of U.S. program design, we refrain for now from modeling policy changes in other countries. Incorporating the carbon policies under development in other regions would have other general equilibrium effects; however, they are unlikely to change the relative impacts of the U.S. policy scenarios.

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[8] Tax data are an area targeted for improvement in GTAP (Babiker et al. 2001).

[9] After that period, emissions are to be further reduced to 1990 levels, though not below, as specified in the Kyoto Protocol targets.

[10] The latest version of GTAP is 2001,and we are attempting to update the numbers.

[11] These are electric generation, industrial production, commercial activities, and transportation.

We conduct five experiments to assess the relative impact of using an output-based allocation scheme compared with other permit allocation methods. We face two basic issues here: (a) how to allocate pollution permits and (b) how permit revenues enter into the government budget, to the extent the permits are auctioned. The experiments are as follows.

Grandfather + Lump: Permits are grandfathered to all (including final demand),[12] and the government budget is held constant through a lump-sum tax. It is the equivalent of taking back a portion of the lump-sum-rebated permit revenue. (Hence, it is also equivalent to Auction + Lump).

Grandfather + Ltax: Permits are grandfathered to all (including final demand), and the government budget is held constant through a labor tax. This is the equivalent of a lump-sum rebate of all permit revenues.

Auction + Ltax: Permits are sold—no grandfathering—and permit revenues are used to offset the labor tax.

Historical OBA + Ltax: Permits are allocated to firms based on output shares in sectors with intermediate energy demand, sector shares are based on historical emissions, and government revenue is held constant through a labor tax. Those permits not distributed (i.e., those for final demand) flow back into the government budget.

Historical OBA + Lump: Permits are allocated to firms based on output shares in sectors with intermediate energy demand, sector shares are based on historical emissions, and government revenue is held constant through a lump-sum tax. Those permits not distributed (i.e., those for final demand) flow back into the government budget.

Value-Added OBA + Ltax: Permits are allocated to firms based on output shares in sectors with intermediate energy demand, sector shares are based on historical shares of value added, and government revenue is held constant through a labor tax. Those permits not grandfathered (i.e., those for final demand) flow back into the government budget.

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[12] This represents a departure from the Climate Stewardship Act, which excludes consumers and agriculture. However, we found that grandfathering permits to firms only (intermediate demand) made little difference on the major outcomes.

Results

Permit Allocation

For the gratis distribution scenarios, permit allocation occurs in two phases. First, the rule for sector allocations is chosen; we consider historical emissions shares and value-added shares as examples. In both cases, permits are allocated to sectors with primary energy demand (which tends to exclude primary energy producers).[13] Second, those sector allocations are either grandfathered in lump-sum fashion among firms within each sector or made based on output.

The sector allocations for these scenarios are reported in Table 1. Permits representing final demand (residential energy use, representing a little less than 7%) are assumed to be held by the government and auctioned.

Table 1: Sector Shares of Carbon Cap with Historical and Value-Added Rules

Sector	Historical	Value-Added
Agriculture	0.9%	1.3%
Electricity	41.0%	1.4%
Iron and steel industry	1.1%	0.5%
Chemical industry	9.6%	2.9%
Nonferrous metals	0.3%	0.3%
Nonmetallic minerals	1.1%	0.6%
Transport equipment	0.2%	1.9%
Paper, pulp, print	0.9%	1.8%
Trade and transportation	27.9%	2.6%
Air transport	4.4%	0.7%
Other machinery	0.5%	6.7%
Food products	0.9%	2.2%
Wood and wood products	0.2%	0.9%
Construction	0.0%	5.9%
Textiles, wearing apparel, leather	0.2%	0.9%
Other manufacturing	0.2%	0.7%
Commercial and public services	4.0%	62.1%
Total	93.4%	93.4%

Unsurprisingly, the distribution of emissions is quite different from that of the overall economy. The electricity sector accounts for just over two-fifths of national emissions, followed

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[13] This assumption runs somewhat counter to the Climate Stewardship Act, which allocates many of the transport sector permits to the upstream energy suppliers.

by trade and transport with another quarter, and the chemical industry with nearly a tenth. On the other hand, services represent two-thirds of value added; all other sectors have modest shares—less than 10%.

Summary Economic Indicators for the United States

Overall, the 14% reduction induces less than a 1% change in the summary economic indicators for all the scenarios, reported in Table 2. However, the relative effects of the allocation scenarios are illustrative.

As predicted, auctioning permits with revenue recycling produces the smallest welfare loss for the United States, measured in equivalent variation. In fact, this mechanism seems to lead to an increase in the real wage and employment, due to the fall in the labor tax.

Table 2: Percentage Change in Summary Indicators

Indicator for United States	GF Hist + Lump	GF Hist + Ltax	Auction All + Ltax	OBA Hist + Ltax	OBA Hist + Lump	OBA VA + Ltax
Welfare (equivalent variation)	–0.06	–0.07	–0.02	–0.05	–0.05	–0.03
Production	–0.41	–0.44	–0.30	–0.29	–0.29	–0.33
Employment	–0.10	–0.15	0.09	0.00	–0.01	0.02
Real wage	–0.40	–0.59	0.35	–0.04	–0.06	0.04
Labor tax change (percentage points)		0.32	–1.28	–0.05		–0.11
Permit price ($/metric ton C)	$ 29.93	$ 29.87	$ 30.18	$ 40.85	$ 40.84	$ 30.59

Grandfathering permits with the labor tax adjustment entails the largest welfare cost—and the largest drop in the real wage—since the loss of tax revenues from the economic contraction requires an increase in the labor tax rate. For this reason, grandfathering permits with a lump-sum tax adjustment fares better.

The most notable effect of historical OBA is the dramatic rise in the price of permits, which are a third more costly than all of the other scenarios. The revenue adjustments were minor—even slightly negative, because of the greater value of the permits withheld for auction—so there was little difference between the lump-sum and labor tax adjustments. The impacts on overall welfare are similar to those with grandfathering and lump-sum adjustment; however, the impacts on production and on the real wage were much smaller. In other words, the mitigation of the consumer price increases, easing the burden of tax and trade distortions, roughly offset the inefficiencies in allocating emissions reductions (which we discuss subsequently in detail).

Value-added OBA functions a good deal like a consumption tax reduction and therefore approaches auctioning in efficiency (though not perfectly so, since not all sectors generating value added receive allocations). Overall, the welfare cost was only slightly higher than auctioning. This scenario brought about a slight increase in the real wage, due not only to a small drop in the tax rate but also to a more even distribution of the effective output subsidies throughout the economy.

Although the changes in the summary indicators are relatively small, the impacts are more significant when broken down by sector. In these cases, the sector-level differences between the lump-sum and labor-tax revenue adjustments are so minor that we report only the scenarios with revenue recycling.

Carbon Emissions

Nearly all the scenarios had the same impact on the distribution of carbon emissions reductions—with the dramatic exception of historical OBA. In this scenario, emissions reductions shift away from heavy historical polluters (sectors like electricity and other manufacturing) toward other sectors, including agriculture, iron and steel, and services.

Table 3: Percentage Change in Emissions

Sector	GF Hist + Ltax	Auction + Ltax	OBA Hist + Ltax	OBA VA + Ltax
Agriculture	–20.5	–20.6	–23.6	–20.6
Electricity	–13.0	–13.0	–11.6	–13.0
Iron and steel industry	–13.1	–13.2	–15.1	–13.2
Chemical industry	–6.2	–6.1	–5.4	–6.1
Nonferrous metals	–4.7	–4.7	–3.1	–4.6
Nonmetallic minerals	–10.9	–10.9	–11.8	–10.9
Transport equipment	–4.9	–4.9	–4.1	–4.8
Paper, pulp, print	–7.3	–7.3	–7.2	–7.2
Trade and transportation	–19.4	–19.5	–19.9	–19.5
Air transport	–6.4	–6.3	–4.8	–6.2
Other machinery	–4.8	–4.8	–4.4	–4.7
Food products	–12.3	–12.3	–12.4	–12.2
Wood and wood products	–4.9	–4.9	–4.2	–4.8
Construction	–4.8	–4.9	–6.0	–4.7
Textiles, wearing apparel, leather	–6.7	–6.6	–6.5	–6.5
Other manufacturing	–4.7	–4.6	–2.4	–4.4
Commercial and public services	–15.6	–15.7	–19.2	–15.8
Total	–13.9	–13.9	–13.4	–13.9

Output

Corresponding to the emissions impacts, production in historically polluting sectors is significantly higher with historical OBA, with less than half the contraction in output in electricity, chemicals, transport, mining, and minerals. With this shift from output substitution as a means for emissions reductions in the major polluting sectors, the carbon price rises by a third to induce reductions elsewhere. This price rise has the added effect of raising the value of the permit allocations, reinforcing the subsidies.

For example, although agriculture engages in greater emissions reductions with historical OBA, the sector's output is less affected; although it receives fewer permits, the total value is nearly the same. Harder hit are wood products and textiles, which benefit little from the subsidy and are harmed by the higher permit prices and trade exposure.

Table 4: Percentage Change in Output

Sector	GF Hist + Ltax	Auction + Ltax	OBA Hist + Ltax	OBA VA + Ltax
Agriculture	–0.34	–0.24	–0.09	–0.22
Coal	–8.98	–8.96	–8.68	–9.03
Petroleum and coal products (refined)	–4.49	–4.38	–3.96	–4.36
Crude oil	–1.87	–1.79	–1.86	–1.84
Natural gas	–4.81	–4.75	–4.70	–4.80
Electricity	–4.85	–4.76	–1.14	–4.69
Iron and steel industry	–0.54	–0.40	–0.41	–0.44
Chemical industry	–1.70	–1.60	–0.47	–1.62
Nonferrous metals	–0.99	–0.86	–0.46	–0.91
Nonmetallic minerals	–0.97	–0.89	–0.33	–0.92
Transport equipment	0.13	0.27	–0.19	0.25
Paper, pulp, print	–0.31	–0.16	–0.21	–0.17
Trade and transportation	–4.54	–4.43	–0.70	–4.48
Air transport	–3.21	–3.03	–0.67	–3.12
Other machinery	0.45	0.58	–0.33	0.57
Mining	–1.09	–1.01	–0.47	–1.24
Food products	–0.23	–0.07	–0.10	–0.07
Wood and wood products	–0.07	0.02	–0.21	0.01
Construction	–0.16	–0.13	–0.11	–0.15
Textiles, wearing apparel, leather	–0.22	0.01	–0.26	–0.02
Other manufacturing	–1.06	–0.87	–0.12	–0.91
Commercial and public services	–0.06	0.12	–0.13	0.09
Dwellings	0.24	0.33	–0.13	–0.03

Price Effects

For the sectors that use energy and electricity as inputs, their price effects tend to be mirror opposites of the output effects. However, the prices of these energy inputs can help explain some of these output effects.

Table 5 reports the changes in prices received by energy producers. Primary energy prices to producers are exclusive of permits, but consumer (or intermediate producer) costs are inclusive of permit costs.[14] The most notable difference for primary energy producer prices is that the price of refined products falls more significantly with historical OBA, which implies a larger carbon price wedge. Including carbon costs implies significant price rises for energy purchasers, particularly with historical OBA.

Table 5: Percentage Change in Energy Prices

Sector	GF Hist + Ltax		Auction All + Ltax		OBA Hist + Ltax		OBA VA + Ltax	
Permit Cost	Excl.	Incl.	Excl.	Incl.	Excl.	Incl.	Excl.	Incl.
Coal	–7.54	39.79	–7.66	40.21	–7.53	57.48	–7.50	40.98
Petroleum and coal products (refined)	–0.65	9.70	–0.72	9.74	–1.03	13.13	–0.66	9.93
Natural gas	–4.66	10.51	–4.75	10.60	–4.80	16.13	–4.62	10.93
Crude oil	–1.74		–1.79		–1.88		–1.75	
Electricity	7.05		7.08		–0.45		7.17	

The electricity price is inclusive of carbon costs as well as any allocation subsidy. In all but the historical OBA, the consumer price rises significantly—a signal for other sectors to conserve. With historical OBA, the price actually falls, meaning that electricity is cheaper than without the carbon policy. This result helps explain why, despite the higher permit price, the producer price of coal does not fall more than with other scenarios, since the electricity sector provides most of the demand for coal. It also explains why more price pressure is placed on other primary energy sources, since more reductions must then come from those sources.

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[14] Crude oil does not embody permit costs; those requirements are revealed in the refined oil prices.

Trade

Since historical OBA causes the greatest distortion in relative prices, it has the greatest impact on trade. Table 6 presents the change in net exports, evaluated at the base year prices, in millions of dollars. The net export position of the heavy emitters falls much less dramatically (and even rises for electricity). However, some sectors that are relatively more competitive in other allocation regimes see their net exports fall with historical OBA: food and wood products, transport equipment, construction, textiles, and commercial and public services. These sectors face high permit prices and labor costs and few subsidies.

Net exports of primary energy products increase in all scenarios, since domestic demand declines. Overall, net exports fall most with historical OBA and least with auctioning. These general equilibrium trade effects lead to some degree of leakage of carbon-intensive production to other countries.

Table 6: Change in Net Exports

Sector	GF Hist + Ltax	Auction + Ltax	OBA Hist + Ltax	OBA VA + Ltax
Agriculture	–203	–299	–11	–243
Coal	1,677	1,687	1,558	1,651
Petroleum and coal products (refined)	649	636	573	592
Crude oil	4,078	3,996	3,474	3,945
Natural gas	1,091	1,091	1,027	1,068
Electricity	–629	–644	18	–655
Iron and steel industry	–681	–680	–44	–700
Chemical industry	–5,425	–5,604	–1,276	–5,589
Nonferrous metals	–769	–776	–98	–794
Nonmetallic minerals	–611	–616	–113	–629
Transport equipment	1,351	1,481	–691	1,471
Paper, pulp, print	–65	–84	–218	–62
Trade and transportation	–10,466	–10,551	–713	–10,634
Air transport	–2,754	–2,742	–588	–2,801
Other machinery	5,940	6,300	–1,924	6,374
Mining	–82	–83	–28	–139
Food products	295	194	–304	271
Wood and wood products	158	159	–171	175
Construction	115	128	–32	127
Textiles, wearing apparel, leather	368	294	–291	318
Other manufacturing	–432	–467	–60	–469
Commercial and public services	5,924	6,144	–1,313	6,283
Total	–467	–437	–1,224	–439

Carbon Leakage

Carbon leakage is driven primarily by the relative price effects for energy-intensive sectors. Since historical OBA is the only scenario to target those sectors specifically, it proves the most effective at limiting the increase in emissions among trading partners. Value-added OBA offers a slight improvement compared with grandfathering and auction. Thus, OBA has the potential to reduce carbon leakage relative to other methods, but the rule for allocating at the sector level is important for determining this effect.

Table 7 compares leakage in the most important industries, focusing on the two OBA scenarios, since the others are so similar to the value-added allocation.

Table 7: Carbon Leakage in the Largest Emitting Sectors

Sector	*1000 MT C*	*OBA Hist + Ltax*			*OBA VA + L Tax*		
	US Baseline Emissions	*US Change*	*Foreign Change*	*Leaked Share*	*US Change*	*Foreign Change*	*Leaked Share*
Electricity	603,573	−69,825	7,279	10%	−78,327	8,400	11%
Trade and transportation	410,489	−81,883	2,645	3%	−80,230	8,340	10%
Chemical industry	141,209	−7,692	1,793	23%	−8,549	2,993	35%
Air transport	64,697	−3,117	496	16%	−4,043	1,407	35%
Comm. and pub. services	58,605	−11,244	443	4%	−9,240	359	4%
Iron and steel industry	16,351	−2,476	797	32%	−2,157	757	35%
Nonmetallic minerals	16,017	−1,886	603	32%	−1,744	690	40%
Food products	13,894	−1,721	127	7%	−1,697	113	7%
Paper/pulp/print	13,602	−980	150	15%	−980	137	14%
Agriculture	13,271	−3,128	414	13%	−2,728	355	13%
Other manufacturing	2,725	−64	1,020	1583%	−121	1,078	889%
Total	1,376,219	−184,980	16,155	9%	−190,896	24,910	13%

In the electricity sector, historical OBA reduces leakage compared to value-added OBA, but it also induces even fewer reductions. In the chemical sector, the reduction in leakage dominates this effect, resulting in more net reductions for that industry. Not only is leakage reduced in the trade and transportation sector with historical OBA, but domestic emissions reductions are also higher, despite higher output. This result arises due to the higher carbon price and greater input substitution possibilities in that sector, including a shift toward labor. We also note the rather important leakage in other manufacturing under all of the scenarios. The emissions intensity of this aggregated sector seems to be much higher abroad than in the United States, causing a small shift in output to have a relatively large impact on emissions for the

sector. This effect may explain why emissions leakage to manufacturing countries like China does not fall as much with historical OBA as does leakage to other trading partners, like Europe.

Table 8 shows carbon leakage by trading partner for each of the allocation scenarios.

Table 8: Carbon Leakage as Percentage of U.S. Reduction

Country	GF Hist + Ltax	Auction All + Ltax	OBA Hist + Ltax	OBA VA + Ltax
Canada	1.37	1.38	0.94	1.37
Europe	3.18	3.19	1.64	3.17
Japan	0.61	0.61	0.43	0.61
Other OECD	0.30	0.30	0.21	0.29
Former Soviet Union	0.93	0.93	0.76	0.91
Central European Associates	0.68	0.69	0.53	0.68
China (including Hong Kong, Taiwan)	1.91	1.92	1.55	1.88
India	0.25	0.25	0.20	0.25
Brazil	0.19	0.19	0.14	0.19
Other Asia	0.92	0.92	0.48	0.91
Mexico + OPEC	1.03	1.03	0.61	1.02
Rest of world	1.63	1.62	1.14	1.61
Total	13.00	13.03	8.64	12.89

International Impacts

Although historical OBA eases some of the burden of tax and trade distortions compared with grandfathering for the United States, this set of output subsidies seems to have the strongest impact on the welfare of trading partners, Canada in particular. The reason is that reduction in U.S. consumer demand is not compensated by an improvement in competitiveness in the industries with historically large emissions.

These international impacts of U.S. climate policy are presented in Table 9. By our calculations, the magnitudes are all less than one-fifth of a percent of gross domestic product.

Table 9: Percentage Change in Welfare by Country (Equivalent Variation)

Country	GF Hist + Ltax	Auction All + Ltax	OBA Hist + Ltax	OBA VA + Ltax
United States	–0.07	–0.02	–0.05	–0.03
Canada	–0.14	–0.13	–0.19	–0.13
Europe	0.01	0.01	0.02	0.01
Japan	0.03	0.02	0.02	0.02
Other OECD	–0.06	–0.06	–0.06	–0.05
Former Soviet Union	–0.08	–0.08	–0.09	–0.08
Central European Associates	–0.03	–0.02	0.04	–0.02
China (including Hong Kong, Taiwan)	0.02	0.01	0.01	0.01
India	0.03	0.03	0.03	0.03
Brazil	0.01	0.01	0.02	0.01
Other Asia	–0.01	–0.01	0.04	–0.01
Mexico + OPEC	–0.18	–0.18	–0.21	–0.17
Rest of world	–0.07	–0.06	–0.06	–0.06

Conclusion

The use of emissions trading represents an important step in improving the efficiency of environmental regulation. However, the tremendous implicit value of the capped emissions—particularly in the case of carbon—raises important political and economic questions about how to allocate the permits. The practical reality seems that the vast majority of permits will be given away gratis to the regulated industries. If so, can we design the allocation process to mitigate the problems of welfare costs, tax distortions, and carbon leakage?

The answer may be that these goals pose trade-offs. In terms of the overall economic indicators—welfare, production, employment, and real wages—auctioning with revenue recycling is the preferred allocation method. Value-added OBA, which effectively attempts to embed the proportional tax rebate into consumer prices, is a fairly close second by these metrics, improving notably over lump-sum grandfathering.

However, in terms of mitigating carbon leakage, historical OBA is clearly the most effective. For the same reason—that it limits price rises in energy-intensive sectors—it also poses the greatest costs on other sectors. While this result would imply important efficiency losses in a partial equilibrium model, we find that these losses are offset by gains in terms of mitigating tax interactions in a general equilibrium framework, where historical OBA is no more costly in welfare terms than grandfathering.

This raises the issue of whether the sector allocation rule can be optimized to target some set of these goals. For example, what might the optimal subsidies to limit leakage look like, and

what impact might they have on overall welfare?[15] What are the relative roles of carbon intensity, trade exposure, and demand elasticities in determining these subsidies?

Finally, although theory offers some support that OBA can enhance the economic efficiency and environmental additionality of emissions trading in a second-best setting, the question remains whether OBA can pass legal muster under world trade rules.[16] From an economic point of view, taxing the carbon content of imports from countries with lesser climate policies can similarly combat leakage; however, such an import tax is very likely to be challenged in the World Trade Organization. Since allocation is perceived as a component of environmental regulation, not a direct subsidy, OBA may enjoy legal leeway. On the other hand, since OBA can create a significant subsidy to industry, it has the potential for abuse in practice. Indeed, unlike with sector-specific performance standards or emissions trading systems, with broad-based, intersectoral trade, OBA can be designed to offer subsidies that outweigh the direct effect of the regulatory compliance costs. Resolving the question of whether OBA is a legal policy tool (and under what conditions) could have important implications for the efficiency— and inefficiency—of future climate policies.[17]

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[15] This question is a general equilibrium variation of that posed by Bovenberg and Goulder (2000), who calculated the gratis permit shares needed to hold industry profits harmless.

[16] For further discussion, see Fischer et al. (2003).

[17] The European Union has its own "state aid" rules, and the European Commission, in monitoring the national allocation plans, seems to be frowning on explicit updating schemes; however, most plans have aspects of gratis allocation that are not truly lump sum, being conditional on production, and expectations for the second commitment period allocations that create expectations similar to OBA incentives. In the United States, OBA is explicitly allowed—even encouraged—in the formulation of state allocation plans for NO_x trading in the Northeast.

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Appendix: MPSGE Code for Output-Based Allocation

Fossil Fuel Production Activity (Crude, Gas, and Coal)

```
$prod:y(xe,r)$vom(xe,r) s:(esub_es(xe,r)) id:0
o:py(xe,r)q:vom(xe,r)a:gov(r) t:ty(xe,r)
i:pa(j,r)q:vafm(j,xe,r)p:pai0(j,xe,r) a:gov(r) t:ti(j,xe,r) id:
i:pl(r)q:(ld0(xe,r)/pl0(r)) p:pl0(r) a:gov(r) n:ltax(r) id:
i:pr(xe,r)q:rd0(xe,r)
```

Non–Fossil Fuel Production (Includes Electricity and Refining)

```
$prod:y(i,r)$nr(i,r) s:0 vae(s):0.5 va(vae):1
+ e(vae):0.1 nel(e):0.5 lqd(nel):2
+ oil(lqd):0 col(nel):0 gas(lqd):0
o:py(i,r)q:vom(i,r) a:gov(r) t:ty(i,r) a:ra(r)
n:z(i,r)$(sum(fe,vafm(fe,i,r)))
i:pl(r)q:(ld0(i,r)/pl0(r)) p:pl0(r) a:gov(r) n:ltax(r) va:
i:rkr(r)$rskq:kd0(i,r) va:
i:rkg$gkq:kd0(i,r) va:
i:pa(j,r)$(not fe(j))q:vafm(j,i,r) p:pai0(j,i,r) e:$ele(j) a:gov(r)
t:ti(j,i,r)
i:pffi(fe,i,r)$vafm(fe,i,r)q:(vafm(fe,i,r)*pai0(fe,i,r)) fe.tl:
```

Fossil Fuel Composite (Fuel Plus Permit)

```
$prod:ffi(fe,i,r)$(nr(i,r) and vafm(fe,i,r))s:0
o:pffi(fe,i,r) q:(vafm(fe,i,r)*pai0(fe,i,r))
i:pcarb(r)#(fe)q:carbcoef(fe,i,r) p:1e-6
i:pa(fe,r)q:vafm(fe,i,r)p:pai0(fe,i,r) a:gov(r) t:ti(fe,i,r)
```

OBA-Related Side Constraints

```
$constraint:z(i,r)$(nr(i,r)and sum(fe,vafm(fe,i,r)))
z(i,r) * py(i,r) * y(i,r) * vom(i,r) =e= ( - ebar(i,r) * y(i,r)) * pcarb(r);
$constraint:ebar(i,r)$(nr(i,r) and sum(fe,vafm(fe,i,r)))
ebar(i,r) * y(i,r) =e= PctCap(r) * (OBA_Hst * alloc_hst(i,r) + OBA_Va *
alloc_VA(i,r));
```