Appendix E-4

ESTIMATING BOUNDS ON THE MACROECONOMIC EFFECTS OF THE CEF POLICY SCENARIOS[1]

1. *INTRODUCTION AND OVERVIEW*

Scenarios for a Clean Energy Future (CEF) is a partial equilibrium study in that it focuses specifically on markets for energy services. It is also important, however, to consider potential effects of the CEF policies on overall economic performance. The purpose of this Appendix is a) to provide a framework for interpreting the macroeconomic (or second-order) effects that might occur under the types of scenarios analyzed in the CEF, and b) to obtain a range of estimates of these effects associated with the Moderate and Advanced scenarios as described in the CEF study.

It should first be noted that the term macroeconomic is used in several, not always consistent, ways. Beyond meaning economy-wide in general, macroeconomic has several competing connotations in contemporary economics. First, there is the Keynesian idea of short-run, disequilibrium dynamics, with particular emphasis on involuntary unemployment. Examples of this approach are the Data Resources, Inc. and WEFA models. Second is the approach that treats the entire economy as the sum of its *microeconomic* components, assuming market equilibrium and rational consumers and firms. This paradigm underlies the computable general equilibrium models such as those of Jorgenson-Wilcoxen (1993), Goulder (1995), or Edmonds et al. (1992).[2]

In this appendix we will consider results from both types of model in the context of the CEF study. Our primary framework and calculations focus on the second meaning given above of the term macroeconomic and the associated CGE models, because these are appropriate for analysis on the time scales of the CEF, through 2010 or 2020. Because the Keynesian-style macroeconomic models are designed and suited for short-term forecasting, we will also discuss the application of one such model —that of Data Resources, Inc. (hereafter, DRI) —to the analysis of the shorter-horizon effects of certain policies to reduce carbon emissions.

The premises of bottom-up or technology-focused analyses such as the CEF regarding consumers and firms decision-making on energy efficiency as well as the overall performance of markets for energy efficiency differ substantially from those embodied within top-down models of both the CGE and Keynesian varieties. Accordingly, our primary aim in this Appendix is to present and apply a framework within which both types of analysis can be accommodated. We thus begin with a theoretical discussion of the relation between the CEF approach and the equilibrium concept embodied in the CGE models. Next, we apply this discussion to obtain order-of-magnitude estimates of the combined macroeconomic impacts of the CEF policies and the $50 per tonne carbon charge envisioned in the Advanced scenario. These calculations are carried out under conservative assumptions regarding the disposition of the emissions permit revenues. We then go on to review the role of fiscal policy in both CGE and Keynesian modeling of carbon policy. The introduction of carbon taxes or a system of auctioned tradable carbon emissions permits would result in a considerable flow of revenue to the government. This revenue could be returned to the private sector in a number of ways. A large body of literature on the economics of carbon policy has demonstrated that exactly how this revenue is recycled to the economy has a substantial impact on the economic effects of abating carbon emissions through the price mechanism. We summarize the basic ideas and findings of

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[2] For additional discussion of this model, see Fisher-Vanden et al. (1993), MacCracken et al. (1999).

this literature and provide examples of the quantitative implications of other assumptions. Finally, we discuss shorter-term macroeconomic impacts of carbon charges as these have been estimated using the DRI model.

2. INTEGRATING THE TECHNOLOGICAL AND MACROECONOMIC PERSPECTIVES

The economy-wide impacts of energy or carbon policies are unquestionably important in general, and no less so in the particular case of technology-oriented policies as envisioned in the CEF. This point, however, should not obscure the purpose and methodology underlying the technology-based studies. The essential finding of the CEF and related studies is that there are large-scale market and/or organizational failures, in addition to potentially substantial transactions costs, that prevent consumers and firms from obtaining many energy services at least cost.[3] The essential conclusion is that this general problem can be overcome, to a considerable extent, through policies that help correct the market failures, induce productivity-enhancing organizational change, and reduce the transactions cost barriers to the diffusion of energy-efficient technologies.

Interpreted in a macroeconomic context, the point of these studies is that the economy is not on its aggregate production-possibilities frontier. Given that the economy produces both desirable products and services (goods of the kind measured by the GDP) as well as environmentally undesirable by-products (bads as indicated by carbon emissions, for example), the production possibilities frontier is an abstract, aggregate representation of the mix of goods and bads that can be produced from a fixed set of input resources. Points *within* this frontier are suboptimal because starting from such a point it is possible to produce more of the goods or less of the bads.

The CEF and similar studies provide empirical evidence that a Pareto improvement is available through intervening in markets for energy services and by adopting various policy measures. Hence, inter-sectoral shifts and adjustments in factor markets that might take place as a result of the policies in question *are accompanied by a net gain in economic efficiency*. This gain is from investments having rates of return that are equal to or greater than the returns available on other investments of comparable risk. It should be noted that the CEF and similar studies do *not* claim that energy is special with regard to evidence of inefficiency and departure from the frontier. Other departures from economic optimality may also exist and may be related to energy inefficiencies. The focus of the CEF is simply on those energy and carbon dioxide related inefficiencies. Understanding the macroeconomic impacts of these policies requires a framework that incorporates both the estimates of the economic efficiency gain and the trade-off and corresponding economic adjustments that occur by placing a price on carbon emissions.

We believe that many of the criticisms of studies like the CEF are a disagreement with the extent to which the economy is inside its aggregate production frontier, the effectiveness of policies to overcome this situation, or both. While there may be grounds for empirical debate about the aforementioned disagreement, it is important not to confuse this dispute with the general problem of analyzing macroeconomic or general equilibrium aspects of the policies contemplated in the studies. This paper uses the production possibilities frontier as such an analytic framework for discussing and estimating the equilibrium effect of policies such as those analyzed by the CEF.

This does not mean that the issue of disequilibrium is unimportant. When the economy experiences unanticipated and unannounced changes, or shocks, the short-run disequilibrium in factor-markets can

[3] Another distinction in the methodology of these studies is that energy services, not energy consumption, is the operational concept to consumers and firms. Energy services are typically held constant in the bottom-up analyses. In general equilibrium approaches, energy services may adjust as well. Concerns over energy services increasing as a result of efficiency efforts focus on this rebound effect.

be severe. Such was the case in the seventies when oil prices rose dramatically and without warning. When there are large and unexpected shifts in the economic landscape there is no time for planning and market adjustments. Consequently, existing capital may be rendered less valuable and resources temporarily underutilized until the economy recovers. However, the technology-based policies outlined in the CEF would be neither unanticipated or unannounced. Instead, they would be phased-in programs, designed to work in conjunction with normal capital stock turnover to minimize the disruption in investment planning and capital purchases. While there would be inevitable shifts in the output of different industries, there is reason to believe that the prior announcement and phase in would allow for a gradual shift. This might not eliminate the short-run disequilibrium, but would substantially reduce it.

Returning to the general equilibrium issues, the best way to combine results from CGE models with the findings of the technology-based studies such as the CEF is to account separately for movements *towards* the production possibilities frontier that are attributable to policy-induced efficiency improvements and movements *along* the production-possibilities frontier that are due to the trade-offs that arise because of the opportunity cost imposed by resource constraints. These effects can be estimated by examining the models which focus primarily, if not exclusively, on those effects. Movements toward the production possibilities frontier can best be derived from the calculations in the bottom-up methodology. Movements along the production possibilities frontier are implicitly represented by the CGE models and are best inferred from the published studies belonging to that literature. With estimates of these two effects in hand, a comparison of their magnitudes can be made.

Of course, a single model that reflects both of these effects would be preferred. However, this would require a CGE framework that includes a detailed technology representation for the various energy consuming sectors and a parametric representation of utility and production/cost functions that are estimated using methods which account for efficiency.[4] Such a model does not yet exist, although some CGE models have taken steps toward such integration via greater representation of technology detail. For example, the MARKAL-MACRO model is one that embeds a well-known technology optimization model into an aggregate economic model. Use of preexisting models tends to limit the manner in which this integration can take place. The alternative would be to start from scratch. The All Modular Industry Growth Assessment (AMIGA) model is one such CGE model, but has a limited history in the peer reviewed literature (see Hanson 2000a, 2000b).

Returning to the proposed framework, a brief exposition of the production possibilities frontier and associated approaches of economic efficiency are appropriate. In the textbook production possibilities frontier, a set of economic resources (inputs) makes it possible to produce a set of different types of desirable goods and services (outputs), e.g. guns and butter (see Fig. 1a). If production is inefficient, i.e. interior to the production possibilities frontier as shown by point I, any movement which increases either or both outputs (as shown by the straight arrows) results in a Pareto improvement.[5] When the frontier is reached, there is a resource constraint, so that increasing one output requires reducing the other output. This resource constraint imposed at the frontier is the source of *opportunity cost*, the cost imposed in lost output of one type when another type of output is produced instead.[6] When goods are priced, then an optimal allocation exists (represented by the point M), and movement along the frontier in the direction of one of the curved lines occurs until the opportunity cost(s) are equal to the prices.

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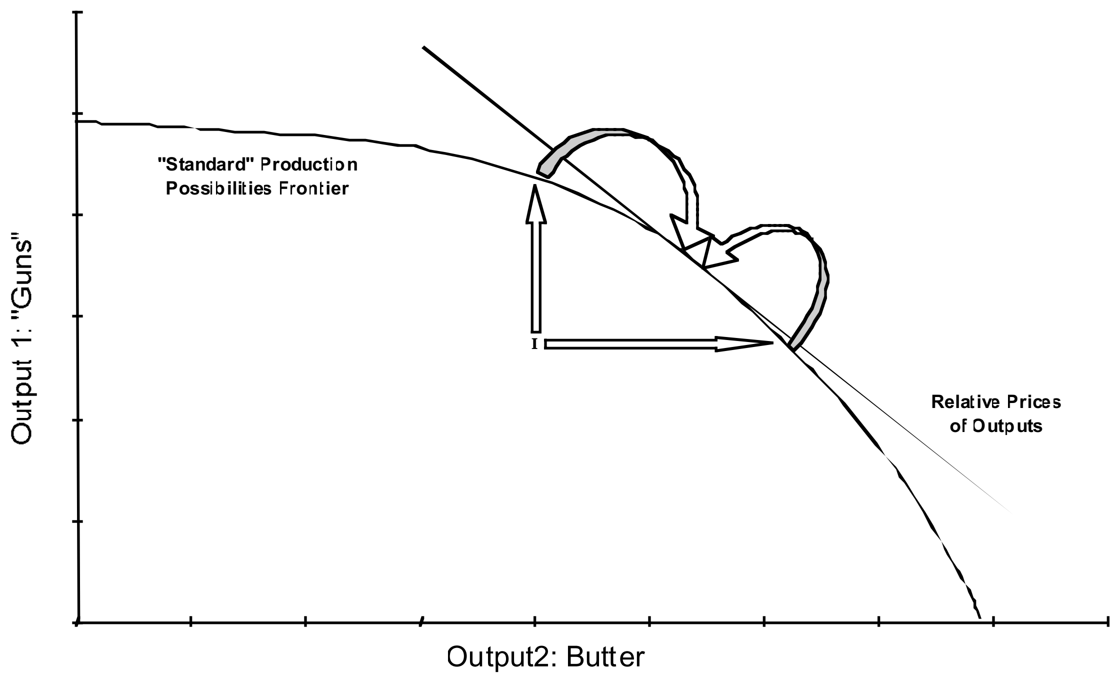
[4] See Green (1993) for a review of these statistical techniques.

[5] This is similar to the standard gains-from-trade-model, when utility curves are overlapping. Any trade that improves at least one player s welfare without decreasing the others is a Pareto improvement.

[6] There are many types of constraints than can create opportunity cost. There may be constraints on R&D spending or the attention of policy makers such that activities to advance technology or promote efficiency in one sector implies that other advances or efficiencies are forgone in other sectors. This type of opportunity cost is due to the constraint. The optimal strategy would be to expand the spending or attention span until all opportunities are fully exploited.

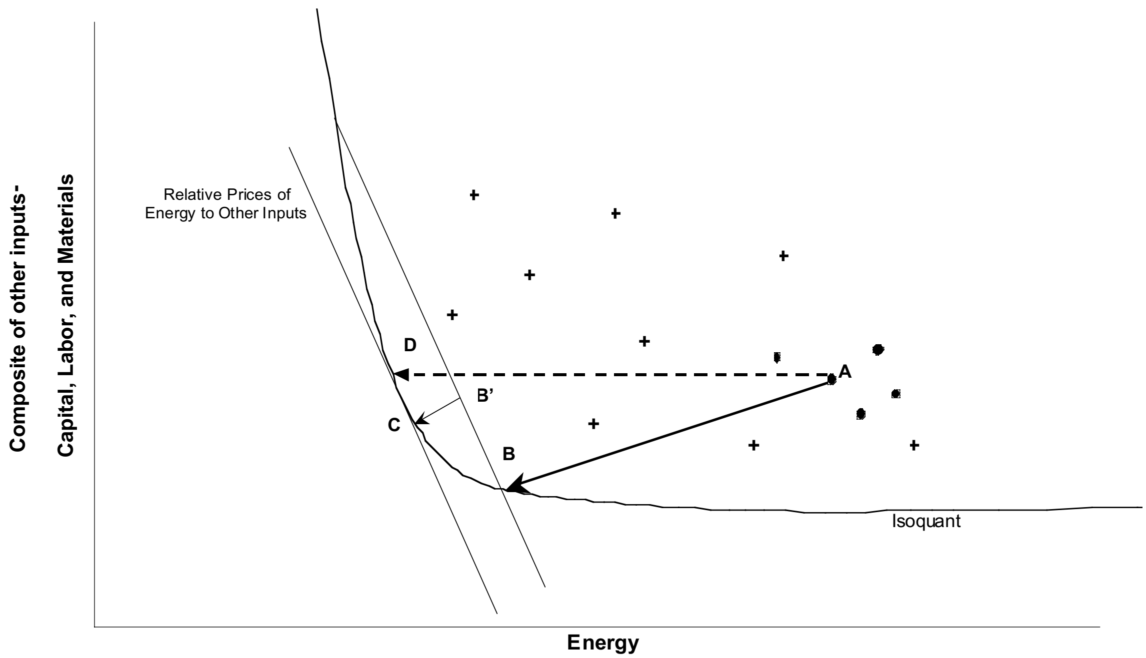
Fig. 1a. Standard Production Possibilities Frontier



Efficiency relative to the production frontier can also be viewed from the input side, instead of the output side.[7] In this context, economic efficiency is the optimization of production activities within a well-defined economic sector. To be economically efficient in this sense requires technical efficiency, i.e. that inputs be used effectively so that a reduction in any input would lead to a reduction in output. This is illustrated in Fig. 1b). The isoquant shows combinations of inputs that can produce a fixed level of output, y. Starting at the inefficient point A, inputs can all be reduced to reach the technically efficient point B, or only a subset of the inputs can be reduced to reach the technically efficient point D. When production is technically efficient, then economic efficiency further requires that cost be minimized in the traditional sense, as at point C. Costs are understood to be as fully specified as possible, i.e. include transaction costs, etc. Note that production efficiency is a necessary but not sufficient condition for economic efficiency. When production is technically efficient, as defined above, then the deviations from cost minimization are called allocative inefficiency, because the reallocation of resources could lower cost while maintaining production. The arrow between B and C in Fig. 1b) represents the cost reduction possible by changing input mix in moving from B to C.

[7] This exposition follows Farrell (1957). This discussion could be extended to revenue functions and profit function by considering the output side simultaneously with inputs (F re and Primont 1995).

Fig. 1b. Standard Production (input) Frontier with Technical and Allocative Inefficiency



In casual use, we speak of an improvement in economic efficiency. From the input perspective, this means technical efficiency improves (input use is lower without lowering output), allocative efficiency improves (input mix changes that lower costs), or both. Corresponding concepts exist on the output side (see Fig. 1a) or simultaneously for inputs and outputs (see F re and Primont 1995 for underlying theory and examples).

There is a 40+ year theoretical and empirical literature on the measurement of these types of efficiency in the fields of economics and operations research. This literature goes beyond the bottom up engineering estimates of energy saving technology. The basic notion of technical efficiency dates back to Koopmans (1951), Debreu (1951), and Farrell (1957). The ideas found in Farrell s influential paper are chronicled in F¿rsund (1999). The published studies on efficiency measurement are too numerous to list here. The bibliography published by Cooper et al. (1999) contains over 1,500 references.[8]

It is important to point out that energy efficiency need not be the same as economic efficiency. Energy efficiency is the optimization of the sub-production functions of an energy aggregate or energy service.[9] As above, costs are understood to be as fully specified as possible, i.e. include transaction costs, etc.[10] Note that *only when an energy service function is separable* from the

[8] This bibliography focuses on a specific branch of this literature that uses a non-parametric linear programming approach called Data Envelopment Analysis (Charnes et al., 1978). There is also a substantial empirical and theoretical literature using statistical and non-statistical parametric methods.

[9] Energy services are the combination of energy with other inputs, usually capital, to produce the desired service. For example, in lighting the energy is electricity while the energy service is illumination, requiring both energy and capital.

[10] When transaction costs are not observed, this may be a reason why a firm is inside the production frontier. Removing or reducing the transactions costs allows the firm to move toward the frontier. When transactions costs are explicit, removing or reducing the transactions costs changes the price line, changing the optimal input allocation. Policies in the CEF are oriented toward, among other things, in reducing the transaction costs via public action when the cost of doing so is less than the sum of the private costs.

overall production function is such sub-optimization possible.[11] The optimization of the overall production function requires the optimization of the underlying function, but not vice-versa. When energy (service) is not separable, then energy efficiency requires the overall cost optimization of the production function, i.e. energy is allocated optimally among all resources, hence energy efficiency is defined to be equivalent to economic efficiency in this case.[12] From this perspective, we see that energy efficiency is a necessary but not sufficient condition for economic efficiency, or optimality. Energy efficiency is not the minimization of energy costs without regard to other inputs. It may be the minimization of energy service costs, with regard to cost of other inputs to energy services, to the extent that energy services are separable.

The connection between energy efficiency and production efficiency has been recognized in the energy economics literature (Huntington 1995). Some empirical connections between energy and economic efficiency can be made in studies of the technical efficiency of energy-intensive production activities. Boyd et al. (1992a, 1992b, 1993, 1994a, 1994b, 1998, 1999, 2000) focus on technical efficiency measurement in energy intensive industries, including steel, cement, glass, and paper. These papers are not the only empirical evidence of production inefficiency in general or efficiency of energy intensive production specifically.

Energy efficiency is just one source of economic efficiency. Fixing problems with energy efficiency does not fix the entire economy. For example, in Fig. 1b) the dotted line illustrates the case where only energy use is reduced from point A to point D. The cost reduction of moving from A to D as shown is greater than the reduction going from point A to point B. This is purely an artifact of the way Fig. 1b) has been drawn. It is an important empirical question to determine the extent to which energy intensity is empirically related to technical inefficiency.[13] The point of the above discussion is to underscore that, when it comes to efficiency, *energy is not special*. However, to interpret the CEF in a macroeconomic context this analysis focuses on the economic efficiency benefits that arise from improvements in energy use.

The environmental context of energy use in the economy requires us to revisit the form of the production possibilities frontier presented in Fig. 1a), since the economy produces some undesirable outputs jointly with the desirable ones. Following F re et al. (1993) we consider a production possibilities frontier with jointly produced desirable and undesirable outputs. Good outputs typically have a value, or price, in the market, while bads frequently are not priced by the market. When bads are priced, either implicitly by regulation or explicitly by permits or taxes, the prices in the context of the production possibilities frontier are negative. Fig. 1c) shows the production possibilities frontier with one aggregate good output, GDP, and one representative bad output, carbon dioxide. Note that over some range of the production possibilities frontier the relationship between GDP and carbon is upward sloping (or equivalently, downward sloping to the left). This reflects the observation that with a given technology and a fixed set of input resources, lowering carbon emissions requires giving up some productive output, i.e. GDP. This is the same as the opportunity cost imposed by the resource constraint in Fig. 1a), except that the joint production assumption of GDP and carbon implies that the production possibilities frontier is upward sloping in some range. Theory also requires that GDP be bounded for a given set of inputs, so the production possibilities frontier has a maximum for GDP. If production is not efficient, then both good and bad

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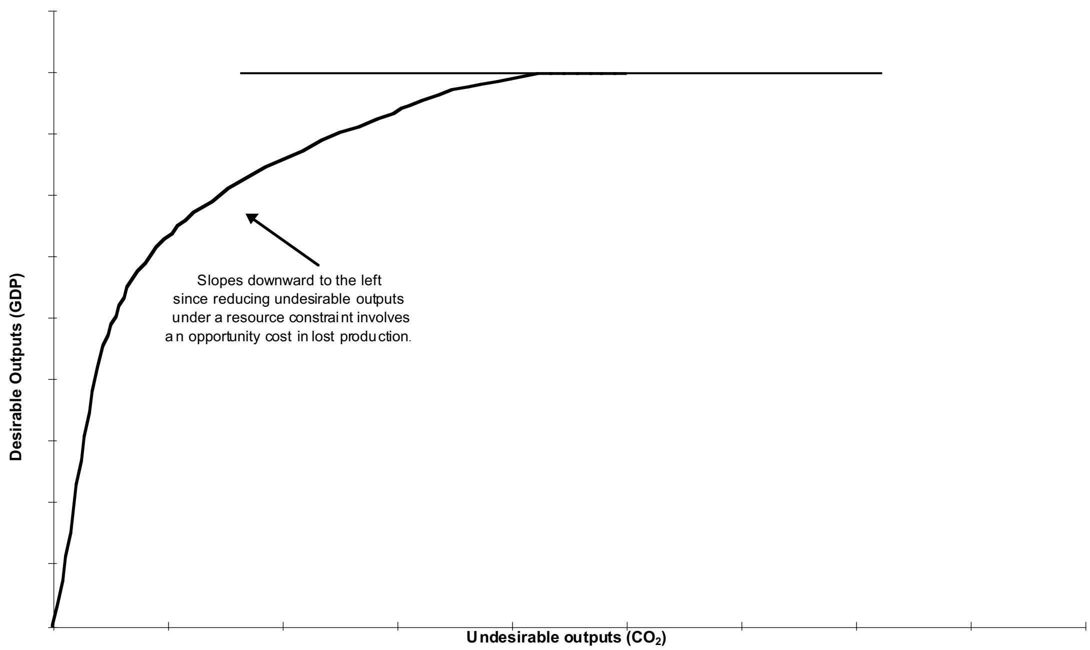
[11] See Blackorby et al. (1978) for a discussion of separability and its implication for economic models. Blundell (2000) provides a theoretical extension of separability that is particularly useful for energy.

[12] Many technologies examined in the CEF are reasonably viewed as being separable, which allows for the definition of energy services.

[13] Many bottom-up studies provide anecdotal evidence that energy efficiency has productivity (efficiency) benefits. Boyd and Pang (forthcoming) use the production efficiency approach and provide a statistical test of this issue for a narrowly defined set of plants in the glass industry. The shape of the curve to the right of the GDP maximum need not be as shown and is of little interest for our purpose here.

outputs may be changed, without incurring any opportunity cost, by eliminating the technical inefficiencies. If the bad output is not priced, i.e. the price is zero, then allocative efficiency is obtained at the maximum GDP.[14] The arrow in Fig. 1c) illustrates the general direction of efficiency change resulting from the CEF, i.e. both a reduction in carbon dioxide and a net increase in GDP. This direction is by design of the policies to seek out economically beneficial carbon reductions.

Fig. 1c. Production Possibilities Frontier with Undesirable Outputs



Just as there are many goods in the economy that comprise GDP, there are also bads other than carbon dioxide. The framework of the production possibilities frontier, described above, is sufficiently general to allow for multiple desirable and undesirable outputs. The assumption of efficient pricing make a monetary aggregate feasible for goods, but no such aggregator is available for bads. [15] The production possibilities frontier approach has been used to address this in a variety of papers (for example, F re et al. 1993, Boyd and McClelland 1999, F re et al. 1999). This paper focuses only on GDP and carbon dioxide emissions, but recognizes that it is a pedagogical simplification.

Another expositional simplification is the treatment of price vs. efficiency effects. It might be argued that CGE models, the parameters of which are either estimated from or calibrated to historical data, include many of the same technologies and behavior that are the focus of the bottom-up studies like the CEF. This raises the question of whether our framework, taking estimates from two different veins in the literature, may result in some overlap or double counting. The extent of double counting depends on whether the estimates for the underlying price responsiveness in the CGE models are biased due to the presence of inefficiency and by how much. If the price response in the

[14] There is no theoretical reason that the maximum GDP determines a unique level of carbon as drawn. The production possibilities frontier could also have a flat spot or nonconvexities resulting in multiple carbon values. The production possibilities frontier to the right of point M is not shown, since we have no specific expectations as to its shape. Theory does require that it be bounded, however.

[15] An aggregator of bads is theoretically possible based on social damages, which would be equivalent to having optimal market prices for all bads.

CGE models includes some shifts in the level of technical efficiency instead of purely a frontier price response, then the results from the two methods cannot be added together. However, Green (1993) shows that there is no way to tell *in which direction an elasticity may be biased* when one fails to account for inefficiency in the underlying data.[16] For this reason, the simple production possibilities frontier is proposed as a reasonable framework to compare the magnitude of these competing effects.

3. *ESTIMATES OF POTENTIAL MACROECONOMIC EFFECTS*

In order to obtain estimates of the different types of effects of the CEF policies on GDP as suggested by the production possibilities frontier framework, we propose a thought experiment having three steps:

(1) Estimate the size of the GDP enhancement resulting from the policies of the CEF s Moderate scenario. This scenario does not include any carbon charge, hence its economic effects are due entirely to its removal of market and organizational barriers to profitable investments and its lowering of transactions costs throughout the economy. These improvements in economic performance represent a pure gain to the economy, a gain that is possible because the economy is initially inside its production-possibilities frontier.

(2) After the Moderate scenario s GDP increment has been realized, introduce the $50/tonne carbon charge that is part of the Advanced scenario, but include none of the other policies of the Advanced scenario. The literature on CGE models reports the results of various runs of those models with alternative carbon charges. Using these estimates, it is possible to calculate a predicted drop in GDP resulting from the carbon charge alone. The difference between the GDP gain of the Moderate scenario and this estimated GDP loss from the carbon charge is a *lower bound* for the GDP gain that could be achieved from the Advanced scenario, because none of the other productivity-enhancing policies of the Advanced scenario is included in the calculation.

The simulations of a $50/tonne carbon charge that we apply assume what is known as lump-sum recycling of the revenue that would accrue to the government from such a charge under an auctioning system. This means that the revenues are returned to consumers or firms in such a way as to induce only an income effect and no substitution among goods and services. As we note in the Introduction, this is a conservative assumption in that it rules out possible gains in economic efficiency from using these revenues to reduce other tax distortions. We discuss this point more completely in Section 4.

(3) The potential GDP gain from the Advanced scenario (measured as the Net Direct Savings[17] under that scenario) amounts to an upper bound on the GDP gain that could result from the Advanced scenario. The Advanced scenario includes technological change policies that shift the production-possibilities frontier beyond what it is under the Moderate scenario as well as technological change induced by the $50/tonne carbon charge. However, the Net Direct Savings estimated by the CEF does not account for a possible shift along the production-possibilities frontier brought about by the carbon charge. (It is a premise of both the Moderate and Advanced scenarios that the energy services provided under the scenarios remain generally the same as in the baseline case.) Hence, the Net Direct Savings calculated under the Advanced scenario is an upper bound for the GDP

[16] In practice, the bias may not exist or may be negligible. For example, Boyd and Pang (2000) finds that estimates of economic (technical) efficiency are significant in explaining the variation in energy output ratios. However, the price coefficient when efficiency is added to the regression model is not significantly different from the estimate without the efficiency variable. Their approach is ad hoc and does not address the issues raised by Green (1993).

[17] Net Direct Savings is defined as [t]he difference between the energy bill savings and the direct costs (annualized incremental technology investment costs plus the program implementation and administration costs) (CEF 2000).

augmentation effect of the Advanced scenario. Subtracting the same GDP loss associated with the $50/tonne carbon charge as in step (2) from the Advanced scenario s Net Direct Savings gives an estimate of the GDP change under the Advanced scenario that takes account of the substitution effect induced by the carbon charge.

This methodology is illustrated in Fig. 2. This figure displays the different possibilities in schematic form. The economy initially is at point I, inside the production-possibilities frontier that can be reached by the Moderate scenario s policies. Implementation of the Moderate scenario moves the economy to point M, with a corresponding increase in GDP from GDP_0 to GDP_1. The line depicting current relative prices is tangent to the production-possibilities frontier at M, and represents the current situation with no carbon charge. A $50/tonne carbon charge shifts the relative price line and makes it upward sloping. The tangency of the new price line to the production-possibilities frontier is at point B, which represents the best the economy can do under the Moderate scenario but with a $50/tonne carbon charge. GDP falls from GDP_1 to GDP_2, reflecting the tradeoff between carbon emissions and GDP that comes about when there is a charge for carbon emissions.[18] The points A_1 and A_2 represent the two possible interpretations of the Advanced scenario. At A_1 there is no substitution of carbon reductions for GDP caused by the carbon charge, while at A_2 this substitution is taken into account.[19] The Net Direct Savings of the Advanced scenario is represented by the quantity GDP_3 - GDP_0; this quantity represents the upper bound on the GDP effect of the Advanced scenario. The difference GDP_4 - GDP_0 gives the intermediate estimate of the GDP gain of the Advanced scenario when substitution is taken into account.

It remains to estimate the magnitude of the substitution effect resulting from implementation of the $50/tonne carbon charge. The Energy Modeling Forum of Stanford University recently compared results from simulations by the leading energy/economic models of alternative scenarios for achieving the carbon emissions targets of the Kyoto Protocol (Weyant and Hill 1999). The scenarios varied according to how much (and among which countries) international trading was allowed to take place. Four trading scenarios were run: (1) no trading of international emissions rights; (2) full Annex I (or Annex B)[20] trading of emissions rights; (3) the double bubble, which considers separate EU and rest of Annex I trading blocs; and (4) full global trading of emissions rights. The outputs of the model runs under these different scenarios (noting that some models were not capable of running every scenario) included estimates of the implicit carbon tax or marginal cost of carbon emissions reductions associated with the particular scenario and model, as well as the corresponding estimates of GDP reductions. These estimates are displayed on Table 1.

[18] Note that although measured GDP falls as the economy moves from M to B, economic *welfare* can improve because society values the additional environmental services that are obtained at point B. See DeCanio (1997) for a full discussion.

[19] A recent study of productivity in OECD countries supports the notion that countries are inside their GDP - CO_2 production frontier and that this frontier has been shifting as shown during the decade of the eighties, see Boyd et al. (1998).

[20] The Annex I (of the 1992 Framework Convention on Climate Change) countries include the U.S., OECD-Europe, Japan, CANZ (Canada/Australia/New Zealand), and the EEFSU (East Europe and Former Soviet Union) countries. The Annex B (of the Kyoto Protocol) list varies slightly from the Annex I list (Weyant and Hill 1999).

Fig. 2 CEF Scenarios and Substitution Effects

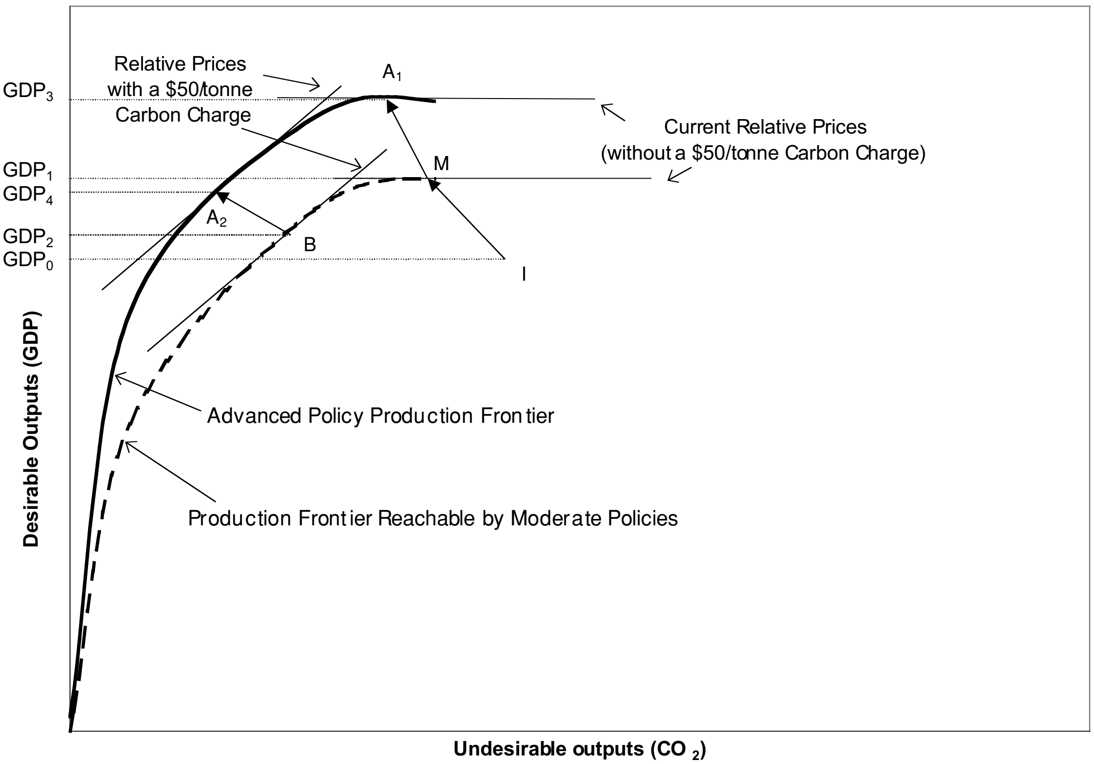


Table 1. U.S. GDP Effects and Implicit Carbon Charges, Various Emissions Trading Scenarios

Model	Implicit Carbon Charge, 1990$				GDP Loss in 2010, billions of 1990$			
	No trading	Annex 1 trading	Double bubble	Global trading	No trading	Annex 1 trading	Double bubble	Global trading
ABARE-GTEM	$322	106	100	23	$182	75	71	19
MS-MRT	236	77	N/A	27	181	88	N/A	28
CETA	168	46	N/A	26	170	59	N/A	38
MERGE3	265	135	N/A	86	90	43	N/A	17
RICE	132	62	N/A	18	84	61	N/A	22
AIM	153	65	45	38	38	26	19	17
G-Cubed	76	53	28	20	35	20	- 4	5

Sources: EMF-16; Weyant and Hill 1999; Weyant 1999. The Oxford model was not included because it is not a CGE model. G-cubed is a hybrid general equilibrium/macro-econometric model because it does consider some unemployment and financial effects. Some other EMF-16 model results are not listed because they did not calculate GDP effects.

To estimate the GDP loss associated with a $50/tonne carbon charge, we calculated a GDP response curve for each model indicating the expected response of GDP to various carbon trading values. We determined this curve by a quadratic extrapolation using the Annex I trading and global trading scenarios as reported by EMF-16. (These are the scenarios with carbon trading values that bracket or are close to the \$50/tonne level.) For each model, the origin and the two estimates of implicit carbon charge and GDP loss determine a unique quadratic response curve.[21] The curves must pass through the origin because, by construction, CGE models show no deviation of GDP from the baseline if no carbon tax is imposed. The figures from Table 1 were converted to 1997\$ using the GDP deflator (Council of Economic Advisers 1999, Table B-3). The results, with the mean and median of the estimates, are displayed in Table 2.

Table 2. Estimated 2010 GDP Loss (1997\$) Associated with \$50/tonne Carbon Charge, Quadratic GDP Response Curve, EMF-16 Data

Model	*Estimated GDP Loss (billions of 1997\$)*
ABARE-GTEM	39
MS-MRT	54
CETA	66
MERGE3	4
RICE	55
AIM	22
G-Cubed	16
Mean	**37**
Median	**39**
Source: EMF-16; see text.	

To complete the thought experiment, these estimated GDP losses can be compared to the GDP *gain* from the Moderate and Advanced scenarios as calculated by the CEF. The net result is that the gain in GDP brought about by the efficiency-improving policies of the Moderate scenario offsets or is roughly equal to the median loss of GDP caused by the substitution induced by the \$50/tonne carbon charge. The combined impact of the Advanced scenario and the substitution effect is a slight gain in GDP if either the mean or median estimate of the substitution effect is used. The comparisons are shown in Table 3.

[21] The unique quadratic passing through the three points (0,0), (x_1, y_1), and (x_2, y_2) is given by the equation

$$y = \left[\frac{y_1 x_2 - y_2 x_1}{x_1^2 x_2 - x_2^2 x_1}\right] x^2 + \left[\frac{x_1^2 y_2 - x_2^2 y_1}{x_1^2 x_2 - x_2^2 x_1}\right] x$$

Table 3. Estimated 2010 GDP Changes from Different Policy Combinations, Billions of 1997$, Various Models, EMF-16 Data

	EMF-16 Model								
	ABARE-GTEM	MS-MRT	CETA	MERGE3	RICE	AIM	G-Cubed	**Mean**	**Median**
$GDP_1 - GDP_0$ (CEF Moderate Scenario)	$40	40	40	40	40	40	40	**40**	**40**
$GDP_2 - GDP_1$ (GDP Substitution Effect)	-39	-54	-66	-4	-55	-22	-16	**-37**	**-39**
$GDP_2 - GDP_0$ (CEF Moderate + Substitution)	1	-14	-26	36	-15	18	24	**3**	**1**
$GDP_3 - GDP_0$ (CEF Advanced Scenario)	48	48	48	48	48	48	48	**48**	**48**
$GDP_4 - GDP_0$ (CEF Advanced + Substitution)	9	-6	-18	44	-7	26	32	**11**	**9**
Source: See text, Fig. 2.									

The Advanced scenario projects Net Direct Savings in 2010 of $48 billion. Thus, the net GDP change after accounting for macroeconomic substitution effects lies between $ - 26 billion (the lowest of the estimates of $GDP_2 - GDP_0$) and $48 billion (the estimate of the GDP gain from the Advanced scenario without any GDP substitution effect). If the substitution effect is added to the GDP gain from the Advanced scenario, the change in GDP ranges from $ -18 billion to $ 44 billion. The mean and median estimates of the CEF Advanced scenario + Substitution Effect are $11 billion and $9 billion, respectively. The conclusion for 2010 is that the GDP increase that arises from efficiency improvements, as estimated by the CEF analyses, are of similar magnitude as the substitution effect from a $50/tC carbon trading permit. In 2020 the CEF estimates of the GDP benefits from efficiency improvements are larger than those in 2010, hence these efficiency benefits are greater than the substitution effect estimated here.

4. THE IMPORTANCE OF FISCAL POLICY: "RECYCLING" CARBON CHARGE REVENUES

The discussion above encompasses only the substitution effects of carbon charges. As noted in the Introduction, however, a system in which tradable carbon emissions permits were auctioned to emitters would result in a potentially large amount of revenue flowing to the government. The alternative would be to "grandfather" the permits, i.e., allocate them without charge to emitters. As we now describe, the use of the revenue in the case of auctioning would have potentially significant implications for the macroeconomic impacts of carbon charges.[22]

The starting point for fiscal policy in the neoclassical framework is that taxes of any sort introduce "distortions" into the economy by changing the behavior of consumers and firms (Auerbach 1985).[23] Distortionary taxes on income or investment entail some (gross) economic losses even if there is a positive net effect once these taxes are used to provide, say, public goods and services.

[22] The topic of this section is discussed at length in Goulder (1996).

[23] Despite the terminology, in some cases "distortionary" taxes can in fact improve economic welfare directly, e.g., emissions taxes that reduce environmental damages.

The fact that a carbon permit system would be introduced in the context of our pre-existing system of taxes suggests the possibility of substituting carbon revenue for the revenue from income or investment taxes. The standard baseline for measuring the efficiency impacts of such policies is lump-sum return of the revenues to consumers and/or firms. In this case, a lump-sum return of the tax revenues would mean that the money is given back in such a way as to induce a pure income gain without causing substitution among commodities or between labor and leisure. This method of revenue recycling leaves existing tax distortions unchanged. This is the assumption made in the simulations we applied in Section 3, and is implicit in our theoretical discussion of Section 2.

By contrast, such existing distortions could be reduced by returning carbon revenue to consumers and firms by reducing *marginal* tax rates on income or investment or both. The fundamental finding in this case is that *this form of revenue recycling lowers the economic costs of carbon charges relative to a policy of lump-sum return.* In essence, environmental policy is made to serve fiscal policy by reducing the economic efficiency losses from existing tax distortions.

A stronger result has been hypothesized and studied extensively: whether using carbon revenues to reduce existing tax distortions can actually lower the overall cost of carbon charges to zero (or make this cost negative). The most recent research shows that this strong double dividend hypothesis is validated when sufficient detail on pre-existing tax distortions is taken into account, and when tax-favored consumption goods are incorporated (Parry and Bento 2000). In addition, it has been demonstrated that auctioning permits and using the revenue appropriately produces significant efficiency gains over systems in which permits are grandfathered (Parry et al. 1999).

A number of studies using CGE models have demonstrated the importance of revenue recycling in determining the economic costs of carbon charges. Goulder (1995) studied the effects of a carbon tax of $25/ton, offset by reductions in period-by-period marginal tax rates (and compared to lump sum reductions). The result of this revenue recycling option relative to lump-sum rebates was significant: in terms of GDP, losses from the carbon tax were reduced by 40-55 percent in the long run, with the largest offset obtained through cuts in personal taxes. Jorgenson and Wilcoxen (1993) studied the effects on real GNP in year 2020 of a carbon tax of $15 per ton imposed in 1990, rising by 5 percent annually. Relative to lump sum rebating, cuts in a labor tax reduced GNP loss by 60 percent - from a 1.7 percent to a 0.69 percent reduction from the baseline GNP forecast. In the case of recycling through taxes on capital, 2020 GNP was actually increased *above* the baseline, by 1.1 percent — a strong double dividend outcome.

Such results reinforce the conservative character of the estimates we presented in Section 3. Using the $50/tonne carbon charge revenues to reduce marginal tax rates in a CGE framework would lower the estimates of the macroeconomic substitution effect that we obtained. In the following section, we will show that revenue recycling assumptions also have significant implications for the analysis of shorter-run effects.

5. TRANSITION IMPACTS: APPLICATIONS OF THE DRI MODEL

A key characteristic of CGE models is the assumption of complete equilibrium —supply equaling demand — in all markets. In particular, while employment in specificsectors can rise or fall, there is no involuntary employment anywhere in the economy. In addition, these models do not contain a representation of money; instead, consumers and firms make choices on the basis of real relative prices. CGE models are generally viewed as representing underlying, long-run features of the economy. When applied to analyzing a policy such as a system of carbon emissions permits, they similarly describe the state of the economy after it has fully adjusted to the intervention.

By contrast, Keynesian models such as that of DRI allow for involuntary unemployment, and represent the money supply explicitly, thereby also permitting the modeling of monetary policy. These models are best suited to analyzing the transition —up to five years —response of the economy to policy changes or economic shocks.

The DRI model contains several measures of overall economic performance. The potential GDP is the economy s maximum potential output, and thus corresponds to GDP as it is represented in CGE models. In addition, the model tracks macroeconomic adjustment costs, which in the case of carbon charges are transition frictions caused by the economy s reacting to higher energy prices.

The DRI model has been applied to several analyses of the effects of introducing carbon charges into the U.S. economy. The most extensive were undertaken by the Energy Information Administration (EIA) of the U.S. Department of Energy in studies of the potential effects of U. S. compliance with the Kyoto Protocol (EIA 1998,1999a). EIA analyzed several scenarios corresponding to different US emissions reduction targets to be achieved on average between 2008 and 2012, phased in beginning either in 2000 (the Early Start case) or in 2005. These scenarios were analyzed using the DRI macroeconomic model in conjunction with the National Energy Modeling System (NEMS).

In both the Early Start and the 2005 start analyses, the scenarios most closely corresponding to the CEF Advanced scenario in terms of carbon reductions ascribed to carbon charges are those in which U. S. emissions rise an average of 24% above 1990 levels in 2008-2012. (In the CEF Advanced scenario, the emission reduction from baseline achieved by the $50/tonne charge is equivalent to a rise of 17% above 1990 levels in 2010.) In the Early Start case, which most closely corresponds to the CEF with respect to timing, achieving this reduction was estimated to entail potential GDP losses (as defined above) of $16 billion (US $1997) and macroeconomic adjustment costs of $33 billion (US $1997) when revenues were returned to consumers in a lump-sum personal income tax rebate. Thus, the total cost to the economy (referred to by EIA as the Actual Loss in GDP) was $49 billion (US $1997). This level of reduction required a carbon price of $63/tonne (in 1997 dollars).[24]

To make an approximate comparison of these results to the CEF s $50/tonne charge, we can scale the estimated GDP losses by 0.79 (i.e., by 50/63).[25] The potential GDP loss, corresponding to the estimates of the CGE models, in the Early Start case is then $13 billion (US $1997), and the Actual GDP loss (including macroeconomic adjustment costs) is $39 billion (US $1997). Thus, in this case the DRI model s predictions of potential GDP loss is in the low end of the range predicted by the CGE models (cf. Table 2, above),. Including macroeconomic adjustment costs places the estimated loss precisely at the median of the range predicted by the CGE models.

Although its timing does not correspond precisely to that of the CEF, the 2005 start scenario is useful to examine because it includes additional detail on revenue recycling options.[26] Achieving the 1990 + 24% target in this case was estimated to entail potential GDP losses (as defined above) of $13 billion (US $1997) and macroeconomic adjustment costs of $84 billion when revenues were returned to consumers in a personal income tax rebate. This rebate was modeled as a lump-sum return (Early 2000). The corresponding losses were again $13 billion (US $1997) in potential GDP and $49 billion in macroeconomic adjustment costs when revenues were returned by lowering the Social Security tax rate applied to both employers and employees. Thus, the total cost to the economy, that is, the Actual Loss in GDP (exclusive of the costs of purchasing international emissions permits) was $97 billion (US $1997) with personal tax rebates and $62 billion (US $1997)

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[24] The GDP losses in the EIA s analysis were in 1992 dollars, and the carbon price in 1996 dollars. These were converted to 1997 dollars using the GDP deflator from Council of Economic Advisers (2000, Table B-7).

[25] This and the corresponding calculation in the 2005 start case assume a linear approximation of the GDP —Carbon charge relationship in the neighborhood of $50-$66 per tonne.

[26] The CEF assumes announcement and anticipatory actions beginning in 2002. Full implementation begins in 2005.

with payroll tax reductions. This level of reduction required a carbon price of $66/tonne (in 1997 dollars).

To compare these estimates to the CEF s $50/tonne charge, we scale the estimated GDP losses by 0.76 (i.e., by 50/66) The potential GDP loss, corresponding to the estimates from the CGE models, is then $10 billion (US $1997) with both forms of revenue recycling, and the Actual GDP losses (including macroeconomic adjustment costs) are $74 billion and $47 Billion, respectively (both in 1997 dollars). Thus, the DRI model s predictions of potential GDP losses are on the low end of the range predicted by the CGE models (cf. Table 2, above). Including macroeconomic adjustment costs places the estimated losses within the range predicted by the CGE models in the case of Social Security tax reductions and slightly above it in the case of personal income tax rebates.

Because the personal income tax rebate was modeled as a lump sum reduction in the EIA s 2005 start analysis, the difference in outcomes between the EIA s two revenue recycling scenarios is an indication that the disposition of carbon charge revenues is as important for transition costs as it is for the long-run costs analyzed by the CGE models. A more dramatic illustration of this importance is given by an application of the DRI model in a study of tradable emissions systems for the U. S. Environmental Protection Agency (Probyn and Goetz 1996). This study analyzed the effects of stabilizing U. S. greenhouse gas emissions in the year 2010 at 1990 levels using various permit systems. (This target allowed carbon emissions to rise approximately 60 million tonnes above their 1990 levels by 2010.) In each scenario, the permit system is introduced in 2000.

Among the permit systems studied was a scenario in which 40% of revenues from permit auctions were returned to consumers in the form of lump-sum rebates, and the remaining 60% recycled to corporations by lowering the statutory corporate income tax rate. The effect of this variation is considerable: the actual GDP less than 0.5% below the baseline throughout the adjustment period, and rises (and remains) *above* the baseline eight years after the system is put in place. The potential GDP (again, corresponding to that measured by the CGE models) *rises and remains above baseline from the time the permit system is introduced.* This result shows that, even in the transition period, potential GDP losses can be avoided altogether —and indeed, potential GDP gains can result —when revenue recycling is used to stimulate investment. This result can be compared with that of Jorgenson and Wilcoxen as described above in Section 4.

To completely analyze the transitional macroeconomic impacts resulting from the carbon charge in the CEF Advanced scenario would require a full simulation using a model such as DRI s. The findings we have reported here, however, suggest that these impacts would be largely, if not completely, dependent on the manner in which the carbon charge revenues were returned to the economy.

6. SUMMARY AND CONCLUDING REMARKS

This Appendix has presented a perspective by which the CEF and similar studies may be placed in a macroeconomic context. In concluding, it is worth pointing out that, as a practical matter, the magnitude of the potential economy-wide energy-efficiency investment contemplated in CEF is small relative to aggregate total investment. The annual total cost (Annualized Incremental Investment Costs + Incremental RD&D Costs + Program Costs) of the Moderate Scenario are less than $20 billion in 2010 and approximately $40 billion in 2020 (in 1997$). The annual total cost of the Advanced Scenario is approximately $40 billion in 2010 and approximately $80 billion in 2020. By comparison, the AEO99 reference case projects Real Investment at annual rates of $2,011 billion in 2010 and $2,508 billion in 2020 in 1997 dollars.[27] Thus, the CEF scenario costs range between 1% (2010, Moderate Scenario) and 3% (2020, Advanced Scenario) of projected total Real

[27] The 1992 dollars of the AEO99 reference case are converted to 1997 dollars using the 1997 chain-type price index for Fixed Gross Private Domestic Investment (AEO99, Table 20; Council of Economic Advisers 1999, Table B-7).

Investment. The ratios indicate that that the investments induced by the CEF policies are quite small relative to total investment. Whatever the ultimate analytical and quantitative estimates of the macroeconomic effects of energy technology policies, these magnitudes should be kept in mind.

We identified three principal macroeconomic effects that operate under the types of greenhouse gas control policies outlined in the CEF. These three effects may loosely be called the efficiency effect, the (frontier) substitution effect, and the technology shift effect. We used the aggregate results of the CEF study with a simple synthesis of scenario outputs from EFM-16 to assist in estimating the magnitude of these three types of macroeconomic effects, all of which are relevant to the policy discussion. While this Appendix does not represent a complete analysis of greenhouse gas policies, it serves to estimate the general magnitude of these important effects. While a model that integrates the concepts of technical efficiency and price (or opportunity cost) would be preferred, we have derived estimates of these competing effects from models in the open literature that focus on each.° We find that the competing effects are of similar magnitude.° When the estimates are added together the net effect tends to be a small positive impact.° Since theory does not provide guidance as to the size or direction of the possible overlap between the estimates, we believe that this approach provides a reasonable indicator that the magnitude of the net effect is indeed small and probably positive.° Further development of an integrated model and research on the nature of the overlap biases of the price and technical efficiency effects would be desirable to improve upon these estimates.

7. REFERENCES

Auerbach, Alan J., 1985. The Theory of Excess Burden and Optimal Taxation. In A. J. Auerbach and M. Feldstein, Eds., *Handbook of Public Econonmics, Vol. I*, Elsevier.

Blackorby, C., D. Primont, et al., 1978. *Duality, Separability, and Functional Structure: Theory and Economic Applications*. New York, North-Holland.

Boyd G., M. Bock, S. Karlson, M. Ross, 1994a. *Vintage-Level Energy and Environmental Performance in Manufacturing Establishments*, ANL/DIS-TM-15 (May).

Boyd G., M. Bock, S. Karlson, and M. Ross, 1994b. Best Practice Electricity Use in Steel Minimills, *Iron and Steel Maker* (May): 63-7.

Boyd G., M. J. Bock, D. Rosenbaum, and M. Ross, 1992a. *Case Studies of the Potential Effects of Carbon Taxation on the Stone, Clay, and Glass Industries.* ANL/EAIS-TM-91, December.

Boyd, G. A., R. F re, and S. Grosskopf, 1998. International Productivity Growth with CO2 as an Undesirable Output, Eastern Economic Association, Boston MA, 1998 and the Southern Economic Association, New Orleans, LA, 1999.

Boyd, G., R. F re, and S. Grosskopf, 1998. International Productivity Growth with CO2 as an Undesirable Output, Eastern Economic Association.

Boyd, G., S. Karlson, M. Neifer, and M. Ross, 1993. Energy Intensity Improvements in Steel Minimills, *Contemporary Policy Issues,* Vol. 11, No. 3 (July): 88-99.

Boyd, G.A. and J. McClelland, 1999. The Impact of Environmental Constraints on Productivity Improvement and Energy Efficiency In Integrated Paper And Steel Plants, *The Journal of Economics and Environmental Management*, Vol. 38: 121-146.

Boyd, G., M. Neifer, and M. Ross, 1992b. *Modeling Plant Level Industrial Energy Demand with the Longitudinal Research Database and the Manufacturing Energy Consumption Survey Database*, ANL/EAIS-TM-96 (January).

Boyd, G. and J. Pang, 2000. Determinants of Plant Level Energy Intensity in the Glass Industry, forthcoming in *Energy Policy*.

Boyd, Gale, George Tolley, and Joseph Pang, 1998. Plant Level Productivity, Efficiency, and Environmental Performance: An example from the glass industry. Working paper

Charnes, A., W. Cooper, E. Rhodes, 1978. Measuring the Efficiency of Decision Making Units, *European Journal of Operations Research* Vol. 2: 429-444.

Cooper, W. et al., 1999. *Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References, and DEA-Solver Software*. Dordrecht: Kluwer.

Council of Economic Advisers, 1999. *Annual Report of the Council of Economic Advisers, 1999*. Washington: Government Printing Office.

Council of Economic Advisers, 2000. *Annual Report of the Council of Economic Advisers, 2000*. Washington: Government Printing Office.

Debreu, G., 1951. The Coefficient of Resource Utilization, *Econometrica* Vol. 19: 14-22.

DeCanio, Stephen J., 1997. Economic Modeling and the False Tradeoff Between Environmental Protection and Economic Growth, *Contemporary Economic Policy*, Vol. 15 (October): 10-27.

Early, Ronald, 2000. Personal Communication.

Edmonds, James A., and Hugh M. Pitcher, David Barns, Richard Baron, Marshall A. Wise, 1992. Modeling Future Greenhouse Gas Emissions: The Second Generation Model Description. Draft Report, presented to the United Nations University Conference on Global Change and Modeling, Tokyo (October 1991).

Energy Information Administration, 1998. *Impacts of the Kyoto Protocol on U. S. Energy Markets and Economic Activity*, U. S. Department of Energy, Office of Integrated Analysis and Forecasting (October).

Energy Information Administration, 1999a. Analysis of the Impacts of an Early Start for Compliance with the Kyoto Protocol, U. S. Department of Energy, Office of Integrated Analysis and Forecasting (July).

Energy Information Administration, 1999b. *The Annual Energy Outlook 1999* (AEO99), U.S. Department of Energy, Office of Integrated Analysis and Forecasting.

Energy Modeling Forum (EMF), 1993. *Reducing global carbon emissions - Costs and policy options*, EMF-12, Stanford University, Stanford, CA.

F re, R., S. Grosskopf, M. Norris, and Z. Zhang, 1994. Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries, *American Economic Review* Vol. 84, No. 1 (March): 66-83.

F re, R., S. Grosskopf, C. Lovell, and S. Yaisawarng, 1993. Derivation of Shadow Prices for Undesirable Outputs: A Distance Function Approach, *Review of Economics and Statistics,* Vol. 75, No. 2 (May): 374-80.

F re, R., S. Grosskopf, and F. Hernandez, 1999. *Environmental Performance: An Index Number Approach*, working paper.

F re, R. and D. Primont, 1995. *Multi-Output Production and Duality: Theory and Applications*. Boston, MA: Kluwer Academic Publishers.

Fisher-Vanden, Karen, and James A. Edmonds, Hugh Pitcher, David Barns, Richard Baron, Sonny Kim, Chris MacCracken, Elizabeth L. Malone, Ronald D. Sands, and Marshall Wise, 1993. The Second Generation Model of Energy Use, the Economy, and Greenhouse Gas Emissions, Presentation to the Sixth Annual Federal Forecasters Conference, Crystal City (September).

Goulder, Lawrence H., 1995. Effects of Carbon Taxes in an Economy with Prior Tax Distortions: An Intertemporal General Equilibrium Analysis, *Journal of Environmental Economics and Management*, Vol. 29: 271-297.

Goulder, Lawrence H., 1996. Environmental Taxation and the Double Dividend: A Reader's Guide, *International Tax and Public Finance,* Vol. 2: 155-182.

Green, W., 1993. The Econometric Approach to Efficiency Analysis, in *The Measurement of Productive Efficiency: Techniques and Applications,* eds. H. Fried, C. A. K. Lovell, and S. Schmidt. New York: Oxford University Press: 68-119.

Farrell, M. J., 1957. The Measurement of Productive Efficiency, *Journal of the Royal Statistical Society Series A, Gen*eral (120, part 3): 253-281.

F¿rsund, F. R., 1999. *The Evolution of DEA - The Economics Perspective*. Sixth European Workshop on Efficiency and Productivity, October 29-31, Copenhagen.

Hanson, Donald A. and John A. Skip Laitner, 2000a. An Economic Growth Model with Investment, Energy Savings, and CO2 Reductions, presented to Salt Lake City meetings of the Air & Waste Management Association, June 18-22.

Hanson, Donald A., Prakash Thimmapuram, Marc Ross, and John A. Skip Laitner, 2000b. Sector Impacts and Industrial Energy Reductions in the Clean Energy Future Study, presented to Salt Lake City meetings of the Air & Waste Management Association, June 18-22.

Huntington, H., 1995. Been Top Down So Long It Looks Like Bottom Up, *The Energy Journal*

Intergovernmental Panel on Climate Change, Working Group III, 1996. *Climate Change 1995: Economic and Social Dimensions of Climate Change*, eds. James P. Bruce, Hoesung Lee, and Erik F. Haites. Cambridge, CB2 1RP and New York, NY: Cambridge University Press.

Interlaboratory Working Group, 1997. *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond*, (Berkeley, CA: Lawrence Berkeley National Laboratory and Oak Ridge, TN: Oak Ridge National laboratory), LBNL-40533 and ORNL-444, September (URL address: http://www.ornl.gov/ORNL/Energy_Eff/CON444).

Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies [CEF], 1999. *Scenarios for a Clean Energy Future*, prepared for Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy.

Jorgenson, Dale W., and Peter J. Wilcoxen, 1993. Reducing U.S. Carbon Emissions: An Econometric General Equilibrium Assessment, *Resource and Energy Economics*, Vol. 15: 7-25.

Jorgenson, Dale W. and Richard J. Goettle, Daniel E. Gaynor, Peter J. Wilcoxen, Daniel T. Slesnick, 1996. Energy Externalities, Social Cost Pricing and Tax Recycling, *Proceedings of the Climate Change Analysis Workshop,* U. S. Departments of Agriculture, Commerce, Energy and State, and U. S. Environmental Protection Agency, Springfield, Virginia, June 6-7.

Koopmans, T. C., 1951. *Activity Analysis of Production and Allocation.* New York: Wiley.

MacCracken, Christopher N., and James A. Edmonds, Son H. Kim, Ronald D. Sands, 1999. The Economics of the Kyoto Protocol, *Energy Journal*, Special Issue, The Costs of the Kyoto Protocol - a Multi-Model Evaluation.

Parry, Ian W. H., and Roberton C. Williams, III, Lawrence H. Goulder, 1999. When Can Carbon Abatement Policies Increase Welfare? The Fundamental Role of Distorted Factor Markets, *Journal of Environmental Economics and Management*, Vol. 37, No. 1 (January).

Parry, Ian W. H.; and A.M. Bento, 2000. Tax deductions, environmental policy, and the double dividend hypothesis, *Journal of Environmental Economics and Management*, Vol. 39 No. 1 (January):67-96.

Probyn, Christopher, and Will Goetz, 1996. Macroeconomic Impacts of Greenhouse Gas Control Policies, *Proceedings of the Climate Change Analysis Workshop,* U. S. Departments of Agriculture, Commerce, Energy and State, and U. S. Environmental Protection Agency, Springfield, Virginia, June 6-7.

Shackleton, Robert, and Michael Shelby, Alex Cristofaro, Roger Brinner, Joyce Yanchar, Lawrence Goulder, Dale Jorgenson, Peter Wilcoxen, and Peter Pauly, 1992. The Efficiency Value of Carbon Tax Revenues, Energy Modeling Forum Working Paper.

Weyant, John P., and Jennifer N. Hill, 1999. Introduction and Overview, in *The Costs of the Kyoto Protocol: A Multi-Model Evaluation*, Special Issue of *The Energy Journal*.

Weyant, John P., 1999. Personal communication of spreadsheet data underlying Figures 8 and 9 in Weyant and Hill (1999).