White Paper

The Economic Costs of a Market-based Climate Policy

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Executive Summary

Effort to develop a mandatory climate policy is accelerating and it seems likely that a national market-based strategy for dealing with climate change is on the near term horizon. Key provisions are likely to include a cap on selected greenhouse gas (GHG) emissions, an institutional framework for creating a nationwide emissions permit market, a welcoming integration of abatement opportunities from external domestic and international sources, and recognition of a broad range of features designed to soften economic impacts or promote economic efficiency. Prompted by a national sense of urgency, businesses, states and regions also are actively engaged in designing and implementing their own variations on these themes. Together, it is clear that there is growing support for a market-based complement to the technology orientation that characterizes current U.S. policy.

In the parlance of finance, climate change policy poses the ultimate present value problem. The benefits of current policy actions may not materialize for a very long time and discounting them to the present, even at very low discount rates, may not compensate today's costs. However, the continuing atmospheric accumulation of greenhouse gases is projected to have far reaching consequences for the earth's climate in coming decades. Although knowledge of the direct and indirect impacts of climate change is currently incomplete, damages to the environment and economy are inevitable, if not occurring already (Smith, J.B., 2004 and Jorgenson, Goettle, et al., 2004). This inevitability provides the ultimate justification for policy intervention.

There are two failures of the market economy that justify public initiatives on climate change. The first is a technological problem in that firms cannot capture all of the returns on their knowledge and technology investments which results in an economy-wide underinvestment in mitigation options. This underinvestment is compounded by the uncertainty that leads to thresholds on minimum financial performance or potential market size below which firms will not launch R&D or technological initiatives. The second problem arises from the divergence between "private" and "social" prices.

Greenhouse gas emissions are related to the patterns of products and processes in production and consumption and these are strongly influenced by prevailing market prices. Emissions are too high because market prices fail to internalize climate-related damages. When emissions-generating goods and services are priced properly, the benefits of avoided damages are reflected correctly in market prices and, so, reflect their social opportunity cost in use. The pricing arena calls for more direct emissions initiatives because the technology policies designed to remedy the first market failure are ill suited to address fully this second one (and vice versa). It is in dealing with this divergence in private versus social prices that the "cap and trade" mechanism gains its comparative advantage.

The suite of abatement remedies available will play a large part in just how large the ultimate cost of addressing climate change will be. This report joins a number of other economic analyses that have examined the pricing aspect of climate policy. It employs the Inter-temporal General Equilibrium Model (IGEM) of Dale Jorgenson Associates (DJA) to answer this question. While providing estimates of the economic costs of a market-based mitigation policy, there is an added and equally important objective of informing its actual design. IGEM is a dynamic general equilibrium model of the U.S. economy that assumes economic agents operate with perfect foresight. It is unique in its portrayal of the economy's numerous and complex interactions in that it is structured around more general and flexible functional relationships that are econometrically estimated from observed market behavior.

Climate change policy needs to be innovative and entrepreneurial. It needs a broad comprehensive vision. It needs to embrace all legitimate and measurable abatement strategies and all potentially competitive marketable options. It also needs to encompass complementary initiatives (tax policy, for example) that serve multiple objectives, perhaps, even beyond purely environmental concerns. Finally, it needs to succeed in achieving its ends with minimal economic consequence. By focusing on the interplay of policy and the economy, this effort identifies key provisional elements and adjustment mechanisms that serve this variety of needs.

The “policy” of this analysis approximates a modest first step at a comprehensive suite of provisions generally associated with cap and trade programs. After a voluntary and orderly phase-in, greenhouse gas (GHG) emissions are constrained to year 2000 emissions levels by 2010 and held there indefinitely. Not all emissions-generating activities are governed by this cap; households, small businesses and agriculture are exempt. The remaining so-called “covered” activities account for about 85% of all GHG emissions, a coverage level similar to recent proposals in the U.S. Senate.

To facilitate compliance at the least possible cost in the scenario considered here, a national system of tradable emissions permits is established. Under the presumption of revenue neutrality, it is assumed that the allowances are auctioned to private industry with the proceeds then redistributed to households in lump-sum fashion. This is analytically equivalent to the other extreme in which all permits are distributed freely to the private sector with lump-sum taxes offsetting any losses in government revenues.

If marketable and verifiable compliance offsets exist beyond the “covered” processes and products, then up to 15% of the cap allowance can be met by these sources. This includes abatement offsets from households and small businesses, from forest-based domestic sequestration and from international permit trading with Canada, Japan, Australia, New Zealand, the European Union, Eastern Europe and the Former Soviet Union (the Annex I countries of the Kyoto Protocol). Like the allowance trading system, the inclusion of offsets reduces policy costs by recognizing and allowing the possibility of a broader array of lower cost abatement alternatives than is to be found within the scope of covered sources.[1]

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[1] It is important to note that the data underlying the non-CO_2 abatement opportunities and the allowable external offsets from households, small businesses, domestic sequestration and international permit trading represent market-based emissions reductions from legitimate, verifiable sources – reductions which would not have occurred in the IGEM base case (without the policy scenario) and reductions that are additive to those from IGEM at a measurable opportunity cost in terms of the economy’s productive resources.

Finally, the policy scenario allows the banking of permits with no limit on the amount of saving for future use.[2] Banking depends entirely on the time paths of permit prices, reflecting, as they do, present and future abatement costs, and interest rates. Of course, in reality, whether or not banking occurs also depends on uncertainty, which does not exist in the perfect foresight world of IGEM. In a policy without a safety valve (sometimes called a price cap), banking provides an opportunity to hedge against unexpected pricing surprises.[3] To isolate the pure effects of the emissions cap, permit trading and alternative compliance opportunities, banking is considered only as a special case; all other model simulations are performed without banking.

Foremost among the analytical findings is that the economic burden of mitigation policy, while measurable, is small. The U.S. economy easily can accommodate a modest policy; this is evidenced not only in the IGEM simulations but also in the results from the other modeling efforts. By 2020, permit prices in IGEM reach \$6[4] per metric ton carbon dioxide equivalent ($MTCO_2E$)[5] with international permit trading and \$10 per $MTCO_2E$ with only domestic offsets. There are corresponding reductions in real GDP of 0.5% and 0.7%, respectively. By 2040, permit prices are in the range of \$22 per $MTCO_2E$ with a GDP loss of 1.2%. And while a 1.2% impact on a trillion dollar economy is a large number, spread over thirty-four years, this loss entails an almost imperceptible slowdown in economic growth.

At the industry level, energy prices – coal, oil, gas and electricity – are most affected, with coal more so than any other commodity. This is not surprising in that 90% of the year 2000 covered emissions are related to the use of coal (35%), oil (39%) and gas (16%). Domestic crude oil and gas extraction prices decline following the declines in

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[2] Borrowing is not considered in this analysis. It is assumed to be rendered uneconomic by reason of high borrowing costs and-or repayment penalties and by future permit price expectations.

[3] There are reasons why banking might not occur. Uncertainty about the future cost and availability of offsets or about a future change in emissions targets may eliminate the incentive to bank even if everything else is known and correct.

[4] All cost references are in year 2000 constant dollars.

[5] All greenhouse gas prices and quantities are in metric tons of carbon dioxide equivalent ($MTCO_2E$). To covert to metric tons of carbon equivalent (MTCE) prices must be multiplied and quantities must be divided by 3.667 (or 44/12).

overall oil and gas demand. This occurs under the formulation in IGEM that approximates an upward sloping oil and gas supply curve. All non-energy prices increase. Some – chemicals, stone, clay and glass, primary metals, electrical machinery (semiconductors) and services (waste management) – are affected both directly and indirectly as their emissions are "covered" by the policy scenario. Others like agriculture, food, paper, plastics, motor vehicles, trade and finance are affected only indirectly.

The production side of the economy is affected adversely. With the exception of agriculture, food and related activities, all industries, especially those related to energy, experience declines in output volumes. This results from not only higher prices and declining demands throughout the economy but also from the limitations on supply that arise from changes in labor and capital availability and from productivity.

The reactions to mitigation policy do not significantly affect consumption. The proportional reductions in real household spending are much smaller than the effects on overall income, spending and production. By 2020, consumption foregone is in the range of 0.1 to 0.2% of baseline levels and, by 2040, the loss increases to 0.5%. In dollar terms, policy costs are $33 per household in 2010, $158 per household in 2020 and $672 per household in 2040. If there is no possibility of foreign permit purchases, these per household costs rise to $84, $313 and $677, respectively. Nevertheless, at their worst in 2040, foregone consumption is less than the additional amounts households spent in 2007 relative to 2006 on gasoline, heating oil and natural gas due to their rising prices.

Overall, the estimated economic impacts of mitigation policy are small. They could be made even smaller through judicious use of complementary fiscal policies. All simulations in this exercise involve lump-sum transfers of permit and tax revenues. It is well-known that this is the least efficient recycling mechanism and, thus, the outcomes above are potentially larger than would be the case if another more efficient mechanism were employed. While the existence of a so-called "double dividend" is controversial, there is broad consensus that there are better and worse ways to redistribute permit revenues. Mitigation policies such as this ***can*** serve to alleviate even greater distortions elsewhere, for example, in labor and capital taxation. The end result may not be "win-win" for the environment and the economy but almost certainly further lowers the overall costs of mitigation policy.

Likely the second most significant analytical finding from this effort is that the benefits of competitive offsets from external sources are large. Their presence reduces significantly the already small costs and limits on them should not be developed independently from overall cost-benefit considerations. This conclusion also is robust across all the modeling efforts. Allowing the use of offsetting emissions from sources outside the cap – that is, households, small businesses, domestic sequestration and international permit purchases – substantially reduces the economic costs of the mitigation policy. In the longer term (2025-2040), the lower cost abatement options provided by the first 15% of these offsets more than halve the adverse policy impacts. For example, the 1.2% losses in GDP would be more than twice as large were it not for the 15% offsets. Nearer term (2010-2025), if international permit trading is allowed to compete with abatement from households, small businesses and domestic sequestration, the 15% offsets reduce policy costs by more than two-thirds as compared to the halving observed when only domestic alternatives are permitted.

Extending the use of offsets to 50% of the emissions cap even further reduces policy costs. The magnitude of these savings depends on the time horizon and the mix of external abatement options. The contributions of more generous offsets always begin small and increase with time. Offsets from international permit trading are, from the data provided, the cheapest and most plentiful of the external sources. With such trading, the 15% offset limit is reached prior to 2020 after which additional offsets begin to prove beneficial. Extending the offset limit from 15 to 50% reduces the policy scenario costs by an additional 30%, 2010-2025, and by an additional 50%, 2025-2040. If the additional offsets arise solely from domestic sources, these additional savings fall to 3% and 12%, respectively. This is because the external domestic options are only slightly less expensive than the internal compliance alternatives they displace but are much more expensive than abatement "purchased" from overseas.

The evidence indicates that there are diminishing net benefits associated with increasing the level of offsets from external sources. However, arbitrarily limiting their potential contribution below that economically justified only raises overall policy costs. Equally problematic is further restricting, in percentage or absolute terms, the role of these or any other competitive alternatives as the emissions constraint becomes more severe. In a series of simulations in which allowable emissions, post 2020, are reduced below 2000 levels and limits on external offsets follow the new cap, the benefits of more generous allowances diminish, not unexpectedly, as the emissions target is lowered and becomes more severe. If policy costs are a major concern, then any limits on potentially competitive abatement alternatives should be developed in the full context of policy costs and benefits. Holding such limits constant or reducing them clearly only raises the economic costs of mitigation policy and in fact suggests that an expansion of an offsets program might be justified over time (assuming that the offsets represent real, measurable, sustainable and incremental emissions reductions).

Finally, the benefits from external offsets increase as baseline emissions increase. Under higher base case emissions, the reductions in policy costs from the first 15% and the next 35% of these offsets exceed the gains observed under lower base case emissions. This too suggests that such limits should be determined by their economically competitive positions rather than by arbitrary restrictions.

Third, in a modeling first, induced technical change is shown empirically to be increasingly beneficial over time in reducing policy costs, especially those borne by consumers. Policy-related price changes combine with empirically observed biases and trends in innovation to yield first-approximation estimates of induced or endogenous technical change (ITC). For some industries, like electric utilities, this partially offsets the adverse policy impacts on industry prices, demand and output. For others, like agriculture, services and construction, this augments these damages. For the economy as a whole, the net effects of induced technical change are beneficial in that they reduce mitigation costs to the larger economy. For GDP and the capital stock, the economic costs nearer term (2010-2025) are 2 to 6% smaller in the presence of induced technical change. Longer term (2025-2040), these same costs are 7 to 10% smaller. However, it is household consumers who are the principal beneficiaries of policy induced technical change. Were it not for this, costs measured in terms of consumption forgone would be 18 to 22% higher in the near-term and over 25% higher longer term.

These results show induced technical change to be an important complement to the economy's more dominant substitution possibilities. Both help to ease the economic burden of policy adjustments and the benefits from each increase significantly over time. While the contribution of induced technical change is likely to remain much smaller than that arising from input substitution and economic restructuring, the estimated cost savings above should be viewed as a conservative "best" initial guess. Additional benefits are quite possible if mitigation policy induces changes not only in relative prices, which IGEM depicts, but also in the empirical processes of innovation that combine with them. Observed trends in innovation are built into IGEM and are based on the rich and varied period from 1958-2000. While plausible references, these biases and trends are policy invariant in simulation. Moreover, IGEM does not recognize the emergence and subsequent commercialization of specific technologies (e.g., hybrid cars, integrated gasification combined cycle plants, carbon storage, the hydrogen economy, etc.). Thus, the ITC metric within IGEM may not reflect fully the potential for induced technical change that arises from a given initiative. This is especially true if the overall policy design seeks to influence directly these very same mechanisms through, for example, targeted investment tax credits aimed at accelerated reductions in emissions intensities.

Fourth, the findings of this analysis support more extensive near-term policy actions. The economic costs of modest emissions reduction policies are small and easily absorbed. Costs are substantially higher and less readily absorbed when policies become more aggressive, either by intent or by necessity due to higher baseline emissions. The benefits from input substitution, induced technical change and the development of new abatement opportunities such as those envisioned from external offsets materialize only gradually and only in the presence of recognizable market-based incentives. By extension, these signals are best generated by policies that directly affect prices and, thereby, permanently internalize the pricing externalities of climate change. Cap and trade policies, thus, are deemed essential complements to the technology initiatives that target underinvestment in R&D and productive capital.

Gradually more decisive steps, dual pronged and adopted early, prod market systems and behavior in the "right" direction; required actions will become more obvious and urgent as the damages from climate change increase and become more readily identified with their source.. A comprehensive climate change policy, crafted today with little or no cost to the overall economy, offers a valuable head start on the path to securing more substantial future payoffs from innovation, technical change and the creation of new, market-based alternatives. With costs as small as those determined here, there is no compelling reason to delay these future benefits or forcibly compress the schedule of their arrival.

In summary, this report offers a comprehensive analysis of a suite of climate policy initiatives associated with a cap and trade program with the goal of identifying those empirical and design issues that most influence the economic consequences of their enactment. Empirically, present-value policy costs heavily depend on the actual outcomes of household consumption-saving and labor-leisure decisions, the magnitudes of and any induced changes in sectoral demand elasticities and technological trends, and the resulting time paths of permit prices and market interest rates. From a design perspective, mitigation policies can be made much less costly if they jointly promote environmental and economic successes, if all legitimate and verifiable emissions-reducing alternatives are allowed to compete, and if the only limits on the use of competing abatement options are those arising from the marketplace. While these are the important conclusions from the present exercise, the more valuable next step is to place these policy costs within the context of the benefits they are purchasing.

1. Introduction

In facing the challenges of global climate change, the United States has yet to embrace any mitigation policy that involves a so-called “cap and trade” mechanism in which there is a constraint on allowable greenhouse gas (GHG) emissions along with a system of tradable emissions allowances. The reasons for this are numerous and varied (see, for example, McKibbin and Wilcoxen, 1997). Prominent among them is the notion that the nearer term economic costs associated with the imposition of a given “cap” are less than fully compensated by economic benefits occurring in the distant future; that is, the constraint is socially inefficient and sub-optimal. Add to this the complication that the nearer term costs are more readily identified and quantifiable while the longer term benefits are more ambiguous and uncertain and hesitancy on policy action becomes inevitable.

There are two failures of the market economy that justify public initiatives on climate change (Goulder, 2004). To the extent that the anthropogenic portion of climate change is a technological problem, the fact that firms cannot capture all of the returns on their knowledge and technology investments results in an economy-wide underinvestment in mitigation options. This underinvestment is compounded by the presence of uncertainties that give rise to thresholds on minimum financial performance or potential market size below which firms do not launch R&D or technological initiatives. To date, this market failure remains the primary focus of national climate change policy with technology-push being the order of the day.

But climate change is also a problem of the divergence between “private” and “social” prices. Past, present and future GHG emissions are related to the patterns of products and processes in production and consumption and these are strongly influenced by prevailing market prices. Emissions are too high (from, for example, over reliance on fossil fuels and the current mix of energy-consuming technologies) because market prices fail to internalize climate-related damages. When emissions-generating goods and services are priced properly, the benefits of avoided damages are reflected correctly in market prices and, so, reflect their social opportunity cost in use. The pricing arena calls for more direct emissions initiatives because the technology policies designed to remedy the first market failure are ill suited to address this second one (and vice versa). It is in dealing with this divergence in private versus social prices that the "cap and trade" mechanism gains its comparative advantage.

While no one denies the technological aspects of climate change, there is growing awareness of the need for a dual approach with technology-push on the one hand and emissions limits on the other. Businesses, localities, states and regions increasingly are engaged in the design and implementation of emissions control policies that complement their ongoing R&D and technology efforts. Among other things, these involve voluntary or mandatory emissions targets, performance incentives featuring both rewards and penalties and the beginnings of a network of interdependent allowance (permit) and offset markets (see, for example, www.pewclimate.org, "US Climate Action Partnership", "Business Environmental Leadership Council" and "What's Being Done"). These leading-edge policies are extremely well intentioned and, undoubtedly, will yield significant and measurable abatement leading to climate change benefits in the coming years. Still, climate change remains a global problem requiring national and international action and cooperation. It is into this larger framework that these sub-national components need be woven.

Although U.S. policy makers chose not to endorse the Kyoto Protocol, many legislators recognize the merits of a dual approach and the incremental value afforded by U.S. participation in an international "cap and trade" system. As such, several states (including ten in the northeast and six in the west) have initiated cap and trade proposals and at the national level there have been ten greenhouse gas cap and trade proposals put forward just since the start of the 110th Congress in January of 2007.

This analysis joins a small family of analyses that have analyzed U.S. cap and trade proposals. Each of these employs a unique model or model system to estimate their policy's impact on the U.S. economy, in general, and on its consumers, in particular. The emphasis in these analyses is on the economic outcomes of a mitigation initiative, components of it and variations in it.

This analysis follows a similar pattern but with a different focus. Here, the Inter-temporal General Equilibrium Model (IGEM) of Dale Jorgenson Associates (DJA) is used to simulate the economy's reaction to the introduction of a cap and trade system. In this regard, the analysis is like those cited above. However, unlike earlier efforts, the experimental design in these simulations emphasizes the mechanisms of adjustment with particular attention devoted to important empirical questions and broader policy decisions that affect both the nature and magnitude of the observed outcomes. ***It must be recognized that this effort considers only the direct and indirect costs of mitigation policy. The estimated benefits of the avoided damages from climate change policy are not incorporated into the model simulations.*** Moreover, analytical choices in the data and operating assumptions of these simulations are intentionally conservative and are believed by these authors to establish an upper bound on IGEM's estimated policy costs.

Familiar readers know that IGEM is a computable general equilibrium (CGE) model of the growth and structure of the U.S. economy and has been used in previous Pew Center efforts. The first of these analyzed the importance of substitution in ameliorating any adverse economic consequences from climate change or climate change policy (Jorgenson et al. 2000). More recently, IGEM served as an integrating framework for evaluating the economy-wide effects of the potential market damages from climate change (Jorgenson, Goettle, et al. 2004). Because IGEM represents the full range of possible responses to economic change (see the aforementioned Pew Center reports and Appendix B) and because it is econometrically estimated in its entirety from over forty years (1958-2000) of market data, it is well suited to address the broad market implications of climate change policy over the intermediate term. However, like all models, predictions in the very far future involve significantly more uncertainty and ultimately depend on the optimistic or pessimistic assumptions about how technology will change over time.

The remainder of report is organized as follows. Sections 2 and 3 present the policy and data considerations for the IGEM simulations. Section 4 provides an overview of the effects of two pairs of variations on main policy themes – international permit trading and external offset opportunities. Section 5 explores, in detail, the mechanisms of adjustment common to all the model runs. Sections 6 compares key results from this exercise to those obtained from other models developed by Charles River Associates (CRA, 2003), the U.S. Energy Information Administration (EIA, 2003 and 2004), the Massachusetts Institute of Technology (MIT, 2003) and the Research Triangle Institute International (Ross, 2008). Section 7 examines the role of induced technical change in easing the economic burden of adjustment and provides estimates of its magnitude. Section 8 considers the effects of less responsiveness on the part of households with respect to their consumption and leisure decisions. Section 9 focuses on two issues with potentially longer-run implications; these are banking and policy options beyond 2020. Section 10 revisits the details of Section 4 for a base case that entails higher energy and emissions growth over the period 2010-2025. Finally, Section 11 offers a series of conclusions derived from the above for the design and timing of cap and trade policies.

2. Policy considerations

Like any model, IGEM can only approximate the details of a complex and comprehensive cap and trade proposal. There are simply not enough "hooks" and "levers" in IGEM to accurately capture the many fine specifics that are conceivable in policy design. As a result, these simulations consider a variety of key provisions included in many of the proposals put forward to-date. These include the emissions constraint in relation to base case emissions growth, the allocation of emissions permits, compliance alternatives to these permits, namely domestic offsets and international credits, and the possibilities for banking of emissions permits.

The analysis assumes a modest cap on GHG emissions at 2000 levels beginning in the year 2010. It is assumed that the policy is announced in 2005 with an ensuing orderly and voluntary transition to the constrained level of emissions beginning in 2006. The cap references the emissions of six greenhouse gases – carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6) – as measured by their global warming potential (GWP). It is based on the totality of 2000 GHG emissions less non-transportation exemptions for the direct emissions from the residential and agriculture sectors and small businesses emitting less than 10,000 metric tons of carbon dioxide equivalent ($MTCO_2E$). For the purposes of identification, these exemptions are considered as ***non-covered*** (by policy) sources of GHG emissions while the emissions-generating activities of all other entities are considered as ***covered*** sources.

Based on the U.S. Environmental Protection Agency's (EPA's) 2004 emissions inventory (EPA, 2004) and assuming that activities in the commercial sector are a reasonable proxy for small business enterprises in the commercial *and* industrial sectors, GHG emissions from 2010 forward are constrained not to exceed 5,945 million metric tons of carbon dioxide equivalent ($MMTCO_2E$). This is just over 84% of the 7,039 $MMTCO_2E$ of total GHG emissions occurring in 2000 but is greater than the 5,673 $MMTCO_2E$ of GHG emissions arising from 2000's fossil fuel use.

Table 1 shows IGEM's base case emissions and energy growth through 2040 while Figure 1 graphically depicts the magnitude of the emissions constraint. Inputs and outputs in IGEM increase at a decreasing rate in base case simulations as the model tracks toward a zero-growth, steady state post 2060.[6] Emissions from covered sources reach 6,724 $MMTCO_2E$ by 2010, 7,500 $MMTCO_2E$ by 2020, 7,815 $MMTCO_2E$ by 2025 and 8,712 $MMTCO_2E$ by 2040. At 5,945 $MMTCO_2E$, the constraint implies abatement in these respective years of 779 (11.6%), 1,555 (20.7%), 1,870 (23.9%) and 2,767 (31.8%) $MMTCO_2E$. (In steady state, abatement is 3,544 $MMTCO_2E$ or 37.4% of covered emissions).

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[6] In order to solve numerically, IGEM requires a terminal, steady-state condition for the economy toward the end of a base-case or policy simulation. Zero growth for emissions and the overall economy in the long run is part of the model's structure rather than an arbitrary assumption or a belief that emissions will stabilize or decline in the future.

Under the cap and trade proposals currently being considered, allowances are either distributed freely to individual emissions sources or auctioned. If auctioned, the proceeds can fund desirable initiatives, provide transition assistance to heavily affected groups and sectors and, or otherwise ease the economic burden through ear-marked capital grants or direct transfers.

Table 1: Base Case Emissions and Energy Growth

		Average Annual Growth Rates in Percent						
	2000 Levels	**2005-2010**	**2010-2015**	**2015-2020**	**2020-2025**	**2025-2030**	**2030-2035**	**2035-2040**
GHG Emissions - Covered Sectors	**5945**	1.786%	1.244%	0.952%	0.826%	0.754%	0.757%	0.670%
Carbon Emissions from Fossil Fuel Use	**5673**	2.047%	1.353%	1.044%	0.852%	0.777%	0.767%	0.687%
Total GHG Emissions - All Sectors	**7039**	1.681%	1.201%	0.898%	0.792%	0.716%	0.730%	0.648%
Energy Consumption								
Coal	**22.6**	1.198%	0.695%	0.504%	0.410%	0.421%	0.442%	0.436%
Refined Petroleum Products	**38.4**	2.647%	1.811%	1.510%	1.302%	1.186%	1.105%	0.929%
Natural Gas	**23.9**	2.276%	1.486%	0.971%	0.650%	0.508%	0.563%	0.551%
Fossil Fuel Use	**84.9**	2.156%	1.431%	1.096%	0.886%	0.797%	0.788%	0.704%
Energy Production								
Crude Oil and Gas Extraction	**34.6**	1.099%	0.832%	0.771%	0.755%	0.796%	0.836%	0.743%
Electricity Generation	**3802**	2.448%	1.802%	1.490%	1.257%	1.127%	1.026%	0.869%

Emissions levels in millions of metric tons of carbon dioxide equivalent. Fossil fuel levels in quadrillion Btu. Electricity generation level in billions of kilowatt hours.

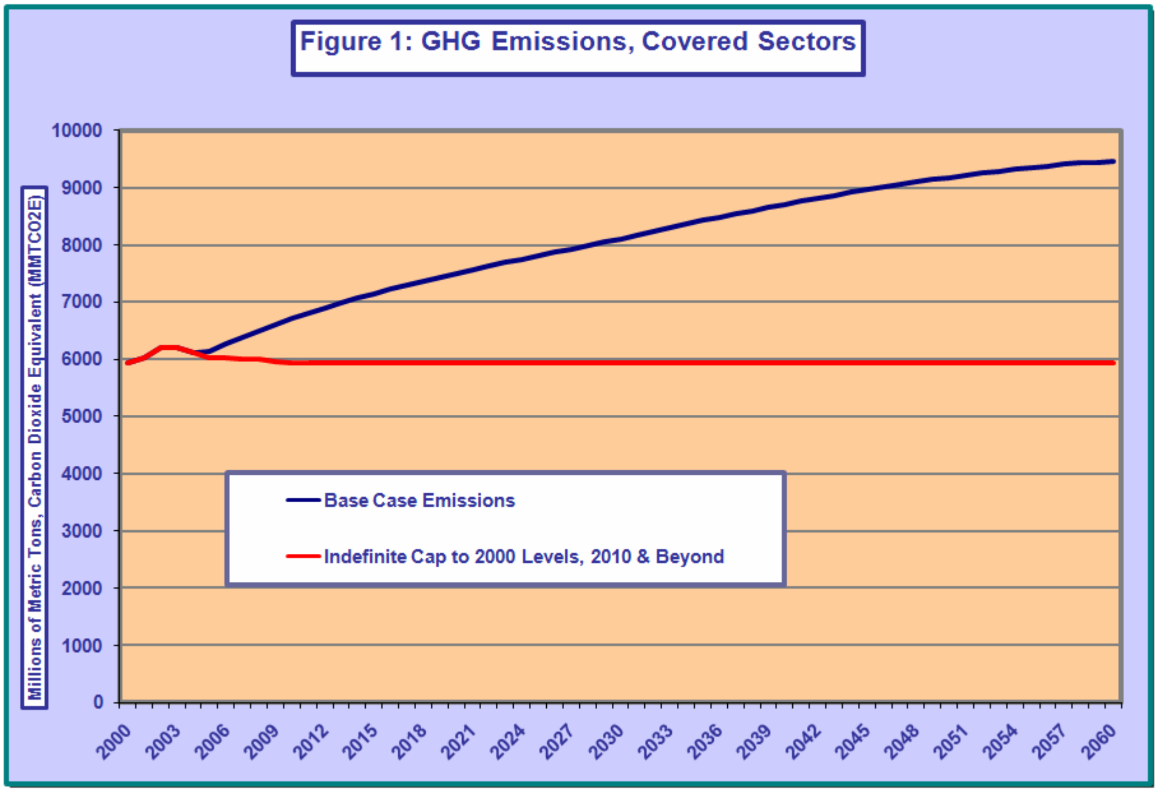


Figure 1: GHG Emissions, Covered Sectors

In IGEM, private sector permit revenues accrue to employee-shareholder households while auction revenues flow to the U.S. government. Demographic details enter into the patterns of consumer commodity demands; at the level of goods and services, there are differing estimated expenditure effects among households but common price responses. At higher levels in IGEM's modeling of the household sector, all effects are common. As there are only "representative" consumers, there are no distinguishing behaviors among IGEM's employee-shareholders who, in the "real" world, would differ by reasons of occupation, industry of employment and corporate ownership. This means that the inter-temporal choices of households (i.e., present versus future spending on consumption *and* leisure) followed by their consumption-versus-leisure decisions are unaffected by the initial allocations of permits to specific stakeholders in specific industries. Put differently, the estimated market outcomes in these simulations are independent of the initial allocation of emissions permits or, equivalently, are invariant among alternative initial allocation schemes.

Under the condition that the scenario is both deficit *and* revenue neutral with respect to the fiscal positions of federal, state and local governments, the following two allocation options yield identical market outcomes in IGEM. In one scheme, all allowances are distributed freely to covered emissions sources. Motivated by economic self interest, these entities use, buy or sell these allowances as market conditions dictate. Governments are assumed to adjust their tax policies through changes in personal exemptions (i.e., through lump-sums) so as to preserve pre-policy deficit and spending levels. There is no presumption that these levels are somehow preferable to any others only that their preservation avoids the complications over what to do with new permit revenues or about any tax losses.

In the alternative scheme, all permits are auctioned with the proceeds flowing to the U.S. Treasury. These revenues are redistributed to households in lump-sums but only to the extent that government deficit and spending levels are maintained. Admittedly, lump-sum redistributions are the least favorable means of revenue recycling and such an assumption begs additional considerations of possible joint tax reforms and even the "double dividend." While the existence and magnitude of a double dividend remain unsettled empirical questions, there is broad agreement that there are better and worse ways to recycle permit revenues (see, for example, Goulder 1994, Jorgenson and Yun 1991, Jorgenson et al. 2000, and Tuladhar and Wilcoxen 1999). Adopting the assumption of lump-sum transfers in this analysis helps insure the upper-bound nature of the policy cost estimates. It simultaneously suggests that modest changes in government tax policies, though beyond the analytical scope of this effort, can serve to ameliorate these costs.

Since these two schemes lead to identical economic impacts, any combination of the two also has these effects. With no behavioral differences among employee-shareholder households and given deficit and revenue neutrality, the estimated market outcomes in these simulations are independent of both the initial allocations of permits among private sector recipients and the initial allocation of permits between the private and public sectors.

In addition to tradable allowances, the scenario evaluated here allows covered sources to meet their compliance obligations by purchasing abatement offsets from "outside" the system. As the "economics" warrant, emissions reductions can be acquired from households and small businesses, from new opportunities for domestic sequestration in agriculture and from participating in enforceable and verifiable international permit trading. While recognizing the likely availability of "cheaper" compliance options, abatement from these alternative sources is limited to 15% of the emissions cap or 892 MMTCO$_2$E. (It is assumed that the permit market will be sufficiently well developed so that the 15% holds for individual entities as well as in aggregate.) However, because of the ameliorative power of finding less expensive compliance opportunities wherever they occur, this analysis also considers a scenario which raised this limit to 50% of the cap or 2974 MMTCO$_2$E. For the intermediate term, this more generous offset allowance is never binding so that all abatement choices are made strictly on a least-cost basis.

The role of emissions offsets in mitigation policy is more solid in theory than it is in practice. In theory, offsetting reduces policy costs by allowing those for whom emissions reduction is cheapest and easiest to "sell" their achievements, beyond compliance, to those for whom the requisite reductions are too expensive or technologically difficult. In practice, GHG offsets need to reduce GHG emissions, efficiently, measurably, permanently and additionally. Efficiency and measurability, however, involve institutional obstacles to accessing offsets. Such things as informational asymmetries between buyers and sellers, the lack of standards and contractual transaction costs are not trivial hurdles to overcome. The permanence issue concerns the sustainability of "today's" offset actions. For example, reforestation counters the effects of deforestation but there is no guarantee of its permanence; newly planted forests eventually can burn, decay naturally or be harvested. The problem of offsets contributing "additionally" is important for policy so that these only count when the reductions would not have occurred anyway and, for modeling, to assure that emissions reductions are not being double counted. That there is, in advance of formal policy, an infant, but rapidly growing, private world market with widely varying offset "prices" is testimony that some offsets are better than others and that market solutions offer the best paths to resolution. (*The Economist*, 2006.)

The data employed in these simulations to portray non-CO_2 abatement opportunities and the allowable external offsets from households, small businesses, domestic sequestration and international permit trading were obtained from analyses in which the issues above were of primary concern. The abatement opportunities external to IGEM represent ***additional*** emissions reductions from legitimate, verifiable sources at measurable costs in terms of the diversion of productive economic resources to these ends.

As IGEM is nationally focused, modeling U.S. participation in a global system of permit trading involves numerous external assumptions with only limited guidance from the literature on world models and assessments. To ascertain the availability of international permits to the U.S. requires answers to the following questions.

1) What is each country’s policy with respect to the sales of allowances domestically versus internationally?
2) What is to be assumed about emissions targets beyond current commitment periods?
3) What limits will potential consuming nations place on purchases of other nations’ excess emissions capacity or, so-called, "hot air?"
4) What behavior will the owners of "hot air" exhibit (e.g., withholding, banking, etc)?
5) What relationship will emerge between and among the developed and developing nations with respect to offsets available from investments in Clean Development Mechanisms (CDMs)?

Even with answers to these, the directions of international permit trading need not always be constant. It is generally predicted that market conditions initially result in the U.S. becoming a net purchaser of international permits. However, it is quite plausible that emerging conditions among Annex I countries (U.S., Canada, Japan, Australia, New Zealand, the European Union, Eastern Europe and the Former Soviet Union) favor the U.S. as a net seller of permits (McKibbin et al., 1998). This opportunity arises because U.S. differentials in baseline conditions, future rates of growth, substitution possibilities and available technological alternatives may allow it to achieve targeted emissions reductions at a lower comparative cost.

With consensus unlikely, adopting any one set of assumptions regarding global permit trading focuses undo attention on market outcomes that potentially are not robust. Accordingly, IGEM simulations are prepared under two extremes. In one case, the U.S. can buy as many permits as are economically justified from those that are available from other Annex I countries. At the other extreme, the U.S. does not engage in international permit purchases because they are either too expensive or not available. In this instance, households, small businesses and domestic sequestration are the only sources of external compliance offsets.

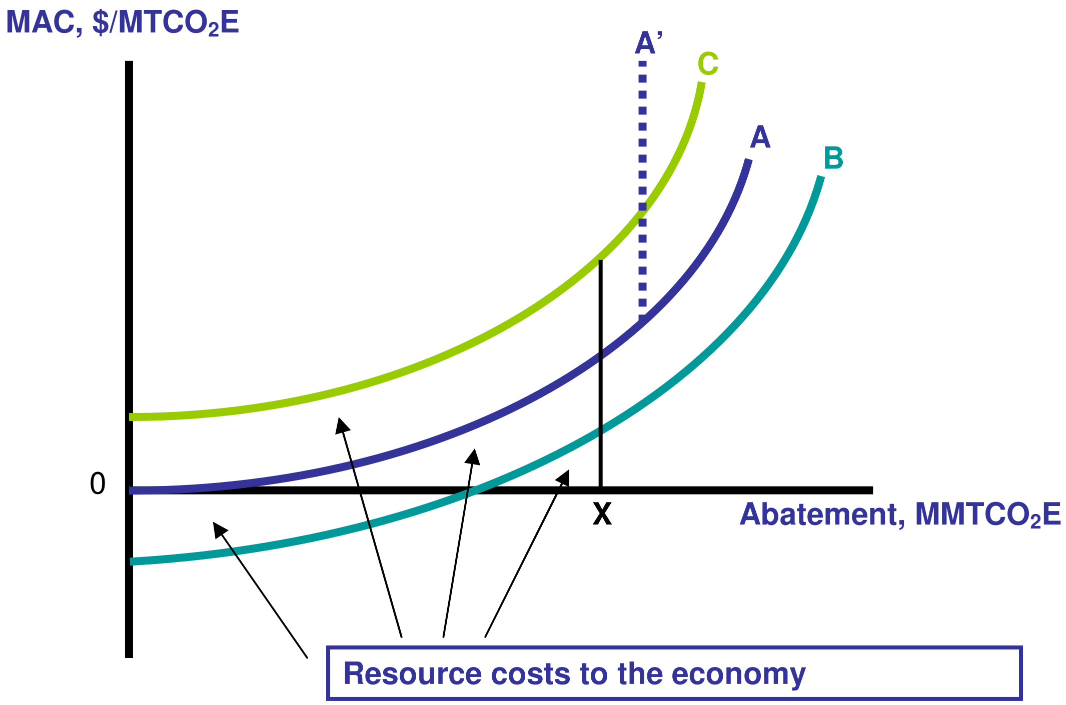
Finally, the analysis does examine the implications of unlimited banking of permits for future use. IGEM, however, is a perfect foresight model, meaning that economic agents have perfect foresight about future policy, technology and their consequences that, in reality, exists only with a great deal of uncertainty. This is coupled with an eventual, long-run, zero-growth steady state requirement for CGE type of economic models. It is unclear whether perfect-foresight banking toward this steady state is a particularly informative assumption given a primary focus on the magnitude of pure, near-term policy costs. Furthermore, whether banking does or does not occur is all about uncertainty. In a policy without a safety valve, for example, banking provides an opportunity to hedge against unexpected surprises. Alternatively, there are plenty of reasons why banking might not occur. For example, any future uncertainty about the cost and availability of offsets or a future change in the emissions target would virtually eliminate the incentive to bank even if everything else in the model's outlook were exactly right. Thus, unlike the other model assessments, the IGEM simulations are conducted in the absence of banking assuming this to be just as plausible an outcome. This isolates the pure effects of the policy's main provisions unencumbered by the consequences of financial arbitrage. Banking and its implications for abatement, permit prices and the economy as a whole are thus considered only as a special case.

3. Marginal abatement cost

Central to this effort is the concept of marginal abatement cost (MAC). This cost measures the sacrifice to the economy of diverting additional scarce resources to the elimination of the next ton of emissions. Both theory and practice confirm this cost to increase as the number of tons abated increases. The relationship between costs and quantities for a given GHG or a particular abatement source is summarized by a marginal abatement cost schedule.

Figure 2 illustrates common properties of the MAC schedules found in current mitigation assessments. Curve A is the more typical representation. For zero abatement, the marginal cost of attainment also is zero. Significant abatement then is available at comparatively low per unit cost. The MAC schedule rises but is initially relatively flat. However, as larger amounts of abatement are required or envisioned, the MAC curve

Figure 2: Marginal Abatement Cost Schedules



becomes more steeply sloped. Incremental emissions reductions become increasingly expensive in terms of their per unit claims on available resources. The vertical (dotted) line drawn from Curve A portrays a possible physical or regulatory limit on the availability of additional emissions reductions from this source; there simply is no more abatement to be had at any price. Curve B shows some positive abatement occurring at a "negative" price. This is an extreme representation of a "no regrets" region. It is indicative of abatement opportunities that currently are "profitable" in the sense of actually releasing resources to more productive uses while simultaneously achieving emissions reductions. They arise most frequently for informational reasons; buyers and-or sellers are simply unaware of the realizable net benefits from their actions. Eventually, Curve B exhibits more traditional behavior but not before the "beneficial" abatement takes place. Curve C depicts a MAC threshold. In this case, abatement from this source is not economically justified until the opportunity cost of abatement reaches some minimum. Only above this minimum is this source a competitive abatement alternative.

A principal benefit from these MAC schedules is that the cumulative area for an abatement level of a given quantity, say X, represents the opportunity cost to the economy of achieving that abatement. Equivalently, the area above less any below a marginal cost of zero measures the economic resources that must be diverted from other productive uses to attain the given emissions reduction. It is this feature that gives the MAC curve value both as an input to and an output from a particular methodology.

Were the emissions intensities of output unresponsive to market or policy driven changes and were all market and technological possibilities fully represented within IGEM's structure, there would be no need for additional information. Marginal abatement cost schedules derived from IGEM simulations would accurately characterize the economic costs associated with all of the economy's substitutions and all of the market and technological changes that follow from the implementation of a particular mitigation strategy. But emissions intensities are not unresponsive to altered circumstances and IGEM does not fully capture all of the market and technical opportunities that serve future mitigation. To remedy this, IGEM is set up to endogenize certain abatement possibilities and their associated costs that viewed as beyond its scope.

The process begins by analyzing each GHG and each economic activity and identifying those mitigation possibilities are that are likely to be adequately represented in IGEM's response to a given policy initiative. These are considered internal to IGEM as are the economic costs associated with their implementation. All other possibilities are external to IGEM and require external abatement cost schedules. Currently, all foreseeable abatement opportunities related to the carbon emissions from covered sources are viewed as internal. This means the marginal abatement cost schedules implicit in IGEM simulations accurately portray all the economic costs of intermediate-term carbon mitigation. External to IGEM are judged to be those abatement opportunities related to household and small business mitigation strategies, non-CO_2 greenhouse gases, domestic sequestration and international permit trading.

The data for these external MAC schedules and the procedure for their incorporation into IGEM simulations are presented in Appendix A. The MAC information for residential and small business abatement is based on IGEM simulations. Here, the opportunities for emissions reductions at every possible permit price are adjusted proportionally downward to reflect the perceived difficulty of bringing these small scale operations into the market system. The details for domestic sequestration are developed from the Pew Center's extensive survey and analysis report, "The Cost of U.S. Forest-based Carbon Sequestration" (Stavins and Richards, 2005). The MAC schedules for non-CO_2 greenhouse gases and international permit trading are from efforts internal to or sponsored by the U.S. Environmental Protection Agency (EPA). Underlying the non-CO_2 aggregate estimates are the analyses of methane and nitrous oxide (Delhotel et al., 2005, and Scheehle and Kruger, 2005) and of HFCs, PFCs and SF_6 (Ottinger-Schaefer et al., 2004). The international abatement opportunities are based on data from global models and assessments adopted by EPA for their use in first approximation, partial equilibrium analyses of climate change policies (Smith, 2005). It must be emphasized these MAC schedules are constructed to avoid the recognized shortcomings of potential offsets. To this end, the non-CO_2 abatement opportunities and the allowable external offsets from households, small businesses, domestic sequestration and international permit trading represent emissions reductions from legitimate, verifiable sources. Equally important, abatement amounts are additive to those from IGEM at measurable costs in terms of the diversion of the economy's productive inputs.

4. The impacts of mitigation policy

The capping of covered-sector GHG emissions is packaged with combinations of offset assumptions to create four scenarios – a 15% limit on external offsets both with and without international permit trading and a 50% limit with and without international trading. The focus here is on evolving permit prices and the structure of abatement and, in turn, their effects on the overall economy. The period of interest is the intermediate term from 2010 through 2040.

Table 2 shows the permit prices for these four simulations expressed in terms of year 2000 GDP purchasing power (see Box 1 on differences arising from the choice of deflator). The sources and the external costs of abatement are summarized for these same years in Tables 3 and 4, respectively.

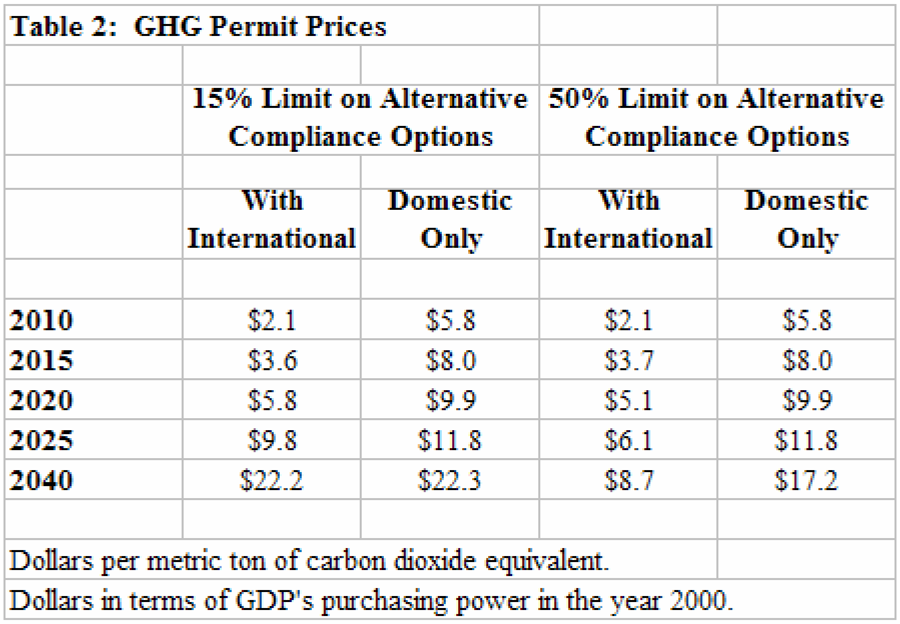


Table 2: GHG Permit Prices

	15% Limit on Alternative Compliance Options		**50% Limit on Alternative Compliance Options**	
	With International	**Domestic Only**	**With International**	**Domestic Only**
2010	$2.1	$5.8	$2.1	$5.8
2015	$3.6	$8.0	$3.7	$8.0
2020	$5.8	$9.9	$5.1	$9.9
2025	$9.8	$11.8	$6.1	$11.8
2040	$22.2	$22.3	$8.7	$17.2

Dollars per metric ton of carbon dioxide equivalent.

Dollars in terms of GDP's purchasing power in the year 2000.

Box 1. Permit Prices and Alternative Price Deflators

Model assessments of market-based mitigation policies primarily focus on three outcomes – the levels of greenhouse gas permit prices, the corresponding emissions abatement they "purchase" and the broader economic consequences that follow. Differences among these across models generally are attributed to the distinguishing features of the methodologies employed – general versus partial equilibrium, estimated versus parameterized, implicit versus explicit adjustment costs, and endogenous (internal) versus exogenous (external) interest rates, technological change and so on. While these features are important in determining the economy's response to the introduction of a particular policy initiative, there are some more subtle differences among models that must be reconciled, or at least identified, to ensure meaningful comparisons among model outcomes. One of these is the recognition of IGEM's accounting for consumer durables where new purchases are part of overall domestic investment while their service flows, like those from owner-occupied housing, are part of household spending and personal consumption (see Appendix B). Another of these is the structure of relative prices in IGEM.

IGEM models expenditures and prices at a variety of levels. All prices in IGEM are expressed relative to an exogenous price of labor. Specifically, this *numeraire* price is the after-tax wage received by households; it establishes not only the price of labor to firms but also the opportunity cost of leisure to households. With productivity both internally and externally determined, the overwhelming majority of prices in IGEM fall over time in relation to the numeraire price of labor. A major exception to this trend is the relative price of greenhouse gas permits which rises as the emissions constraint becomes more severe due to greater necessary reductions from base case levels. The rich array of price indices within IGEM gives rise to an equally rich array of alternative price deflators that can legitimately portray the trend in permit prices from a particular simulation. For within-model analyses, the choice of deflator is immaterial since they are all internally consistent. *The choice of deflator matters only when, for nearly identical* *assessments, one model's permit prices are to be compared to those drawn from another model; then, it is essential that the chosen deflators be identical in concept.*

To illustrate the importance of this, the accompanying table shows permit prices from two IGEM simulations deflated by five possible indices within each. The GDP and consumption price deflators yield similar, though not identical, future price levels. This is reassuring since these final demand measures are the most common among alternative methodologies. However, in terms of total output, inclusive of intermediate goods and services, and in those indices closer to the cost side of the economy (e.g., consumption and leisure and pure leisure), the disparities in permit prices become larger and increase over time. The potential problem is evident. For equivalent levels of abatement, a comparison of IGEM's permit prices relative to the price of leisure (and labor) to another model's prices deflated by that of consumption is both misleading and inappropriate. Thus, as a first check, it is imperative that model comparisons employ identical frames of reference.

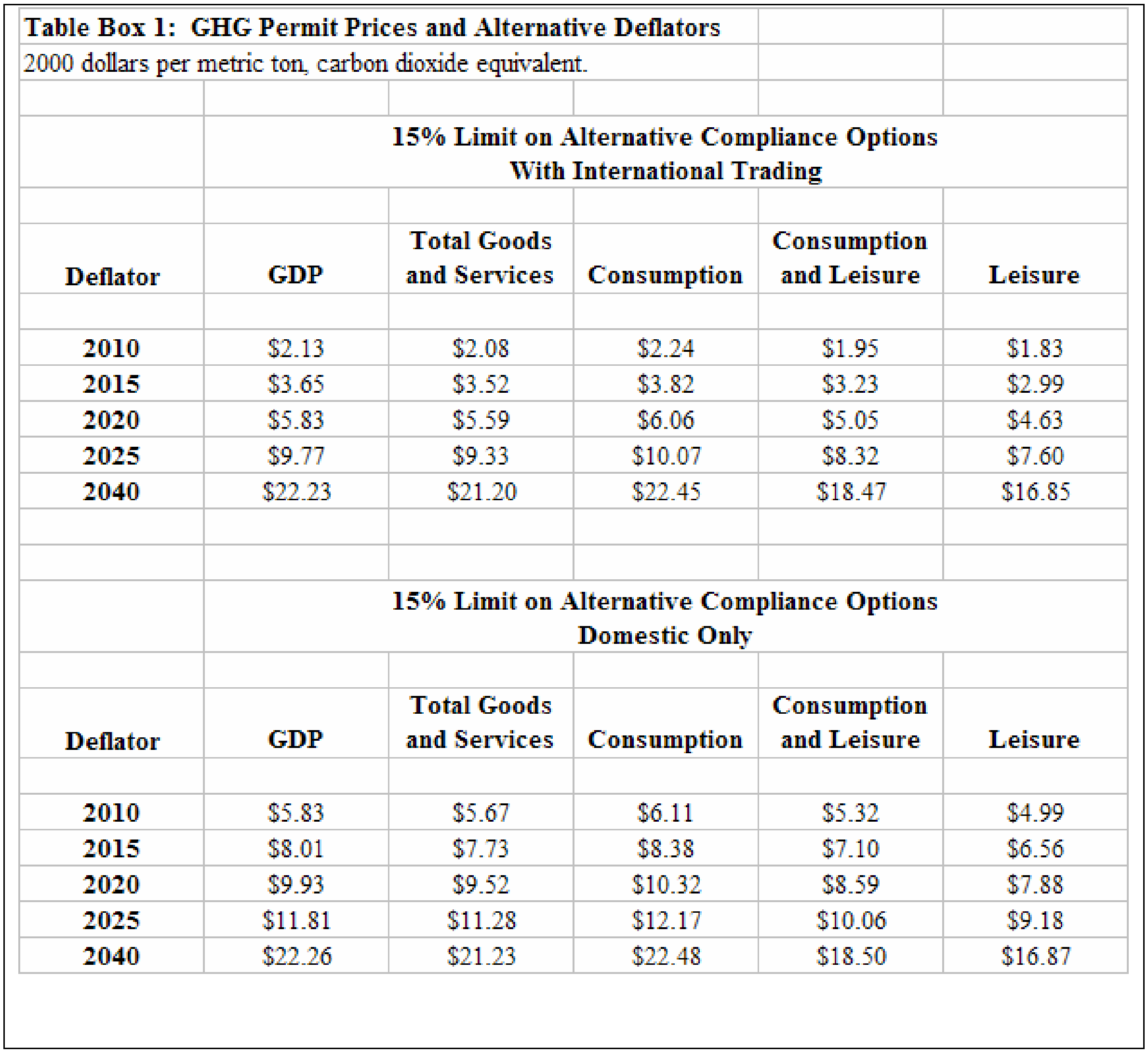


Table Box 1: GHG Permit Prices and Alternative Deflators

2000 dollars per metric ton, carbon dioxide equivalent.

	15% Limit on Alternative Compliance Options With International Trading				
Deflator	**GDP**	**Total Goods and Services**	**Consumption**	**Consumption and Leisure**	**Leisure**
2010	$2.13	$2.08	$2.24	$1.95	$1.83
2015	$3.65	$3.52	$3.82	$3.23	$2.99
2020	$5.83	$5.59	$6.06	$5.05	$4.63
2025	$9.77	$9.33	$10.07	$8.32	$7.60
2040	$22.23	$21.20	$22.45	$18.47	$16.85

	15% Limit on Alternative Compliance Options Domestic Only				
Deflator	**GDP**	**Total Goods and Services**	**Consumption**	**Consumption and Leisure**	**Leisure**
2010	$5.83	$5.67	$6.11	$5.32	$4.99
2015	$8.01	$7.73	$8.38	$7.10	$6.56
2020	$9.93	$9.52	$10.32	$8.59	$7.88
2025	$11.81	$11.28	$12.17	$10.06	$9.18
2040	$22.26	$21.23	$22.48	$18.50	$16.87

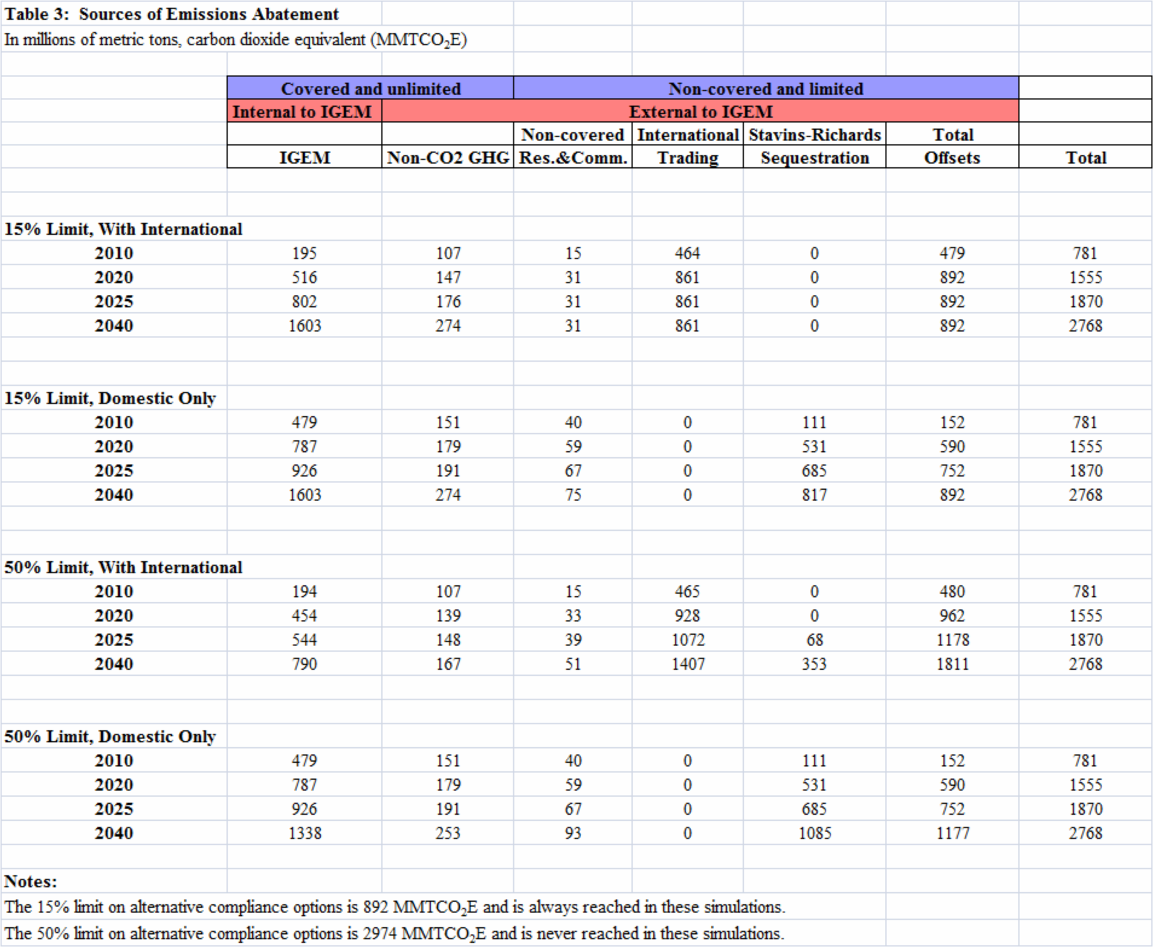


Table 3: Sources of Emissions Abatement

In millions of metric tons, carbon dioxide equivalent (MMTCO$_2$E)

	Covered and unlimited		Non-covered and limited				
	Internal to IGEM	External to IGEM					
			Non-covered	International	Stavins-Richards	Total	
	IGEM	Non-CO2 GHG	Res.&Comm.	Trading	Sequestration	Offsets	Total
15% Limit, With International							
2010	195	107	15	464	0	479	781
2020	516	147	31	861	0	892	1555
2025	802	176	31	861	0	892	1870
2040	1603	274	31	861	0	892	2768
15% Limit, Domestic Only							
2010	479	151	40	0	111	152	781
2020	787	179	59	0	531	590	1555
2025	926	191	67	0	685	752	1870
2040	1603	274	75	0	817	892	2768
50% Limit, With International							
2010	194	107	15	465	0	480	781
2020	454	139	33	928	0	962	1555
2025	544	148	39	1072	68	1178	1870
2040	790	167	51	1407	353	1811	2768
50% Limit, Domestic Only							
2010	479	151	40	0	111	152	781
2020	787	179	59	0	531	590	1555
2025	926	191	67	0	685	752	1870
2040	1338	253	93	0	1085	1177	2768

Notes:

The 15% limit on alternative compliance options is 892 MMTCO$_2$E and is always reached in these simulations.

The 50% limit on alternative compliance options is 2974 MMTCO$_2$E and is never reached in these simulations.

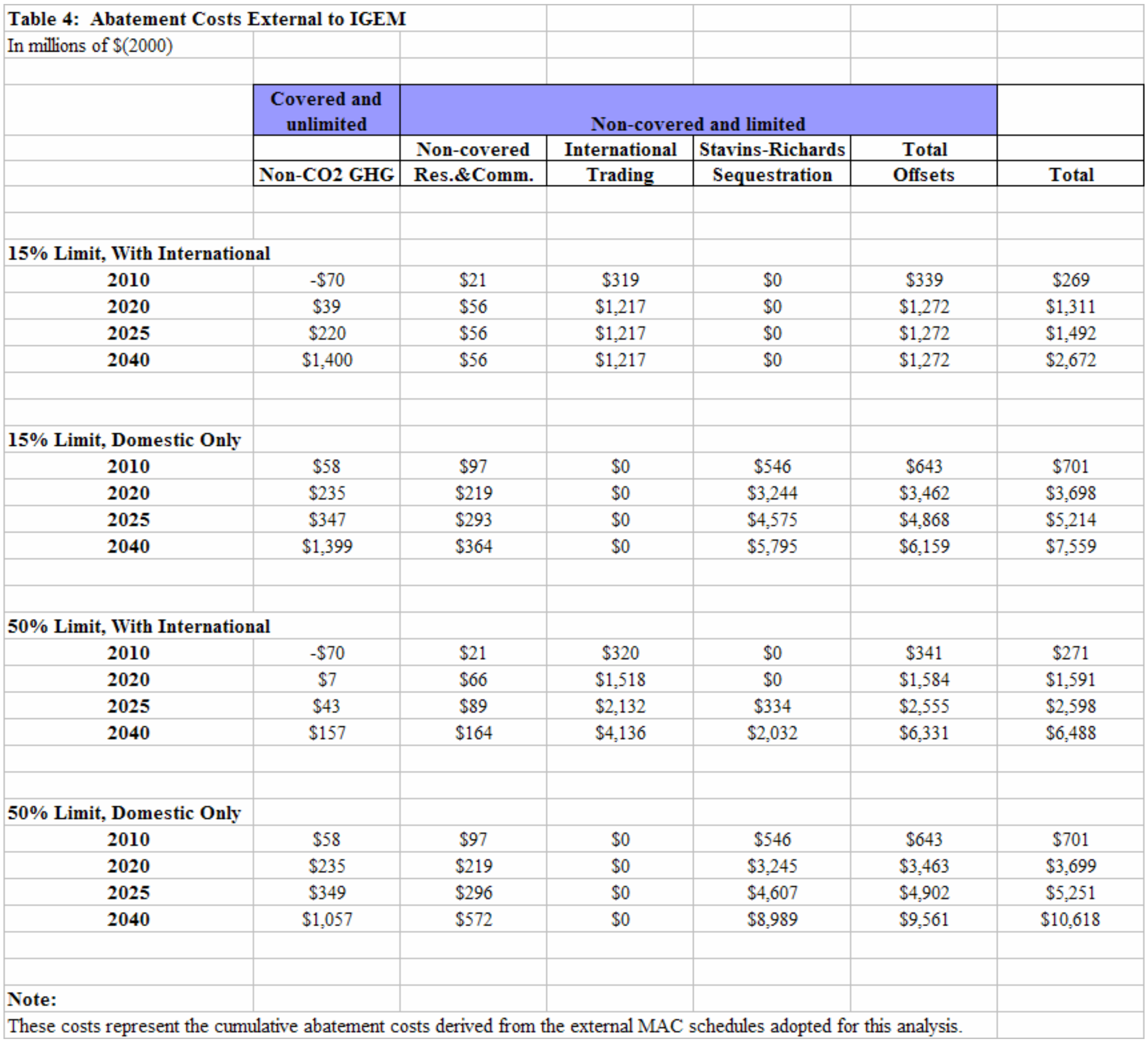


Table 4: Abatement Costs External to IGEM

In millions of $(2000)

	Covered and unlimited	Non-covered and limited				
		Non-covered	International	Stavins-Richards	Total	
	Non-CO2 GHG	Res.&Comm.	Trading	Sequestration	Offsets	Total
15% Limit, With International						
2010	-$70	$21	$319	$0	$339	$269
2020	$39	$56	$1,217	$0	$1,272	$1,311
2025	$220	$56	$1,217	$0	$1,272	$1,492
2040	$1,400	$56	$1,217	$0	$1,272	$2,672
15% Limit, Domestic Only						
2010	$58	$97	$0	$546	$643	$701
2020	$235	$219	$0	$3,244	$3,462	$3,698
2025	$347	$293	$0	$4,575	$4,868	$5,214
2040	$1,399	$364	$0	$5,795	$6,159	$7,559
50% Limit, With International						
2010	-$70	$21	$320	$0	$341	$271
2020	$7	$66	$1,518	$0	$1,584	$1,591
2025	$43	$89	$2,132	$334	$2,555	$2,598
2040	$157	$164	$4,136	$2,032	$6,331	$6,488
50% Limit, Domestic Only						
2010	$58	$97	$0	$546	$643	$701
2020	$235	$219	$0	$3,245	$3,463	$3,699
2025	$349	$296	$0	$4,607	$4,902	$5,251
2040	$1,057	$572	$0	$8,989	$9,561	$10,618

Note:

These costs represent the cumulative abatement costs derived from the external MAC schedules adopted for this analysis.

Several conclusions emerge from these results. First and most obvious, permit prices in all cases continue to rise as the constraint becomes more stringent or, equivalently, as the gap widens between the cap and what covered-source emissions would have been in its absence. Constraints beyond a policy's terminal year need to be explicit because they clearly matter for the permit market and, indeed, for the economy as a whole.

Second, economic agents choose the least expensive portfolio of abatement options subject to their individual availability. Given the MAC schedule for abatement opportunities from non-U.S. Annex I countries and under the condition that the U.S. can acquire whatever abatement is economically justified from this market, abatement overall is cheaper with international permit trading than it is without it. If, for whatever reason, international trading is ruled out (not allowed, not available, not competitive, etc.), the household-small business and domestic sequestration options are more expensive and less competitive. This conclusion, of course, is generic to the availability or lack thereof of any lower cost compliance offset; it is simply that, here, international permit trading is the low cost source.

Third, in these simulations, the limits on external offsets are longer-term considerations. With 15% offsets and international permit trading, the limit is not reached until 2019. With only domestic offsets available, the 15% limit is not binding until 2030. Under the more generous 50% allowances and given the projected growth in baseline emissions, use of these compliance alternatives is unlimited in these simulations.

The importance of these allowable external alternatives cannot be overemphasized. In their absence, long-run permit prices (not shown) would be more than twice as high, as would their economic consequences. Statutory limits on their use also forces more expensive alternatives. Once these limits are reached, there are no period-to-period changes in their utilization or their cost. Permit prices then rise at a more rapid rate as abatement becomes ever more costly. Even the distinction between the lower cost international and higher cost domestic alternatives blurs in the presence of these limits. The convergence of the permit prices in the two cases with 15% limits shows the combination of only domestic options to be competitive with that involving trade *because* these limits were reached. Only much more and now more equally expensive alternatives across the two scenarios remain.

However, with unlimited external offsets over this period, businesses choose the lowest cost options available to them. In both cases, permit prices again are lower because the limits are raised on lower cost options. In addition, the cost differential that initially characterizes the two 50% cases persists. The time paths of permit prices no longer converge because there are no binding limits on any of their underlying abatement options. The availability of only domestic abatement options remains more expensive than when lower cost international permits also can be purchased.

The consequences for the overall economy correspond to the patterns of permit prices and abatement costs. Figure 3 shows the effects on real GDP. Clearly, the economy absorbs this constraint on emissions with relative ease. By 2020, economic losses range from 0.3 to 0.7% of the baseline estimate. By 2040, this range expands to 0.5-1.2%. A 1.2% reduction in GDP over the next thirty-four years involves an almost imperceptible 0.035 percentage point reduction in annual growth. At the lower end of these ranges are simulations in which larger proportions of abatement are provided by lower cost sources. At the upper end, these sources are not available by either statute or assumption. Under the 15% limits, convergence occurs in the GDP changes as offset possibilities are exhausted and only higher cost options remain. Under the 50% limits, the economy definitely benefits from these more generous offsets but the paths diverge as the 50% limits are not binding. Allowing only domestic offsets becomes increasingly expensive over time because international permit purchases serve almost as a "backstop" in insulating the economy from the costs of mitigation.

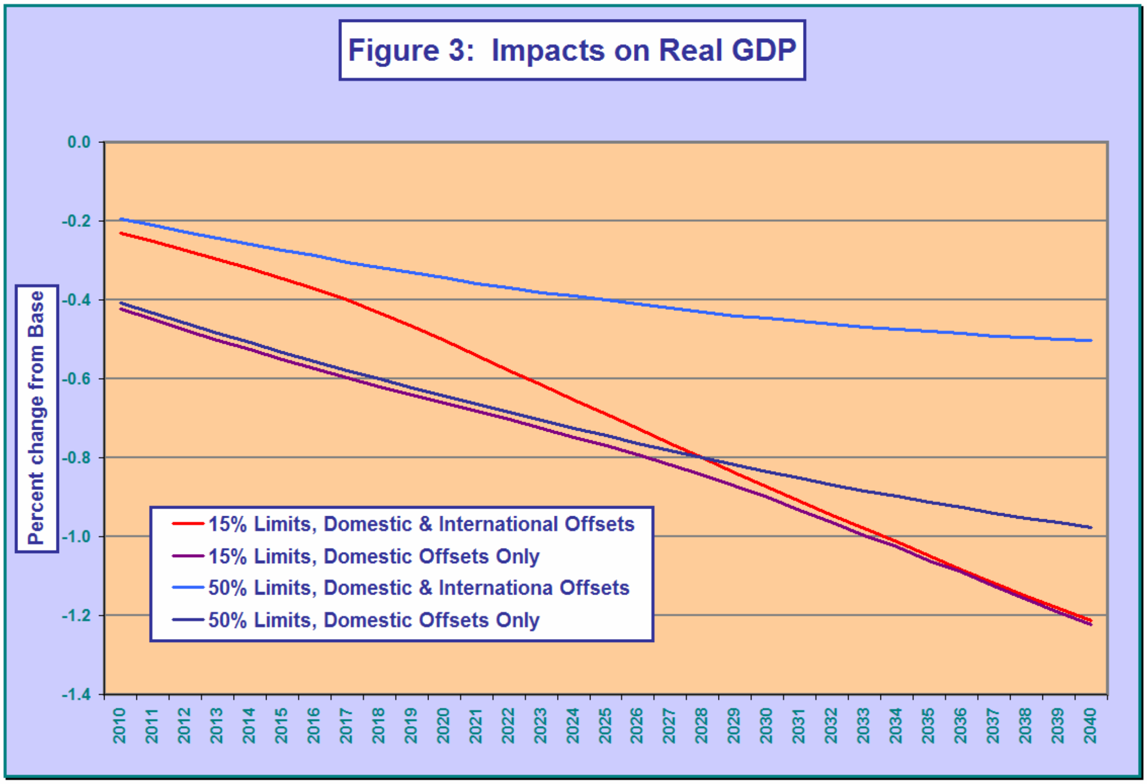


Figure 3: Impacts on Real GDP

As discussed below, the impacts on GDP are spread across all its components with the effects on household spending being proportionally among the smaller. Table 5 shows the effects on real consumption, both in aggregate and per household. The proportional reductions in consumption are, ultimately, less than half of those of GDP. By 2020, the consumption loss is just over 0.1% when trading allows international purchases and just over 0.2% when international trading is not allowed. By 2040, the losses are just over 0.5% when external offsets are limited to 15% of the cap. Under more the more generous offset provision that allow up to 50% of compliance to come from offsets, the losses in consumption range from just under 0.3% to just under 0.5%.

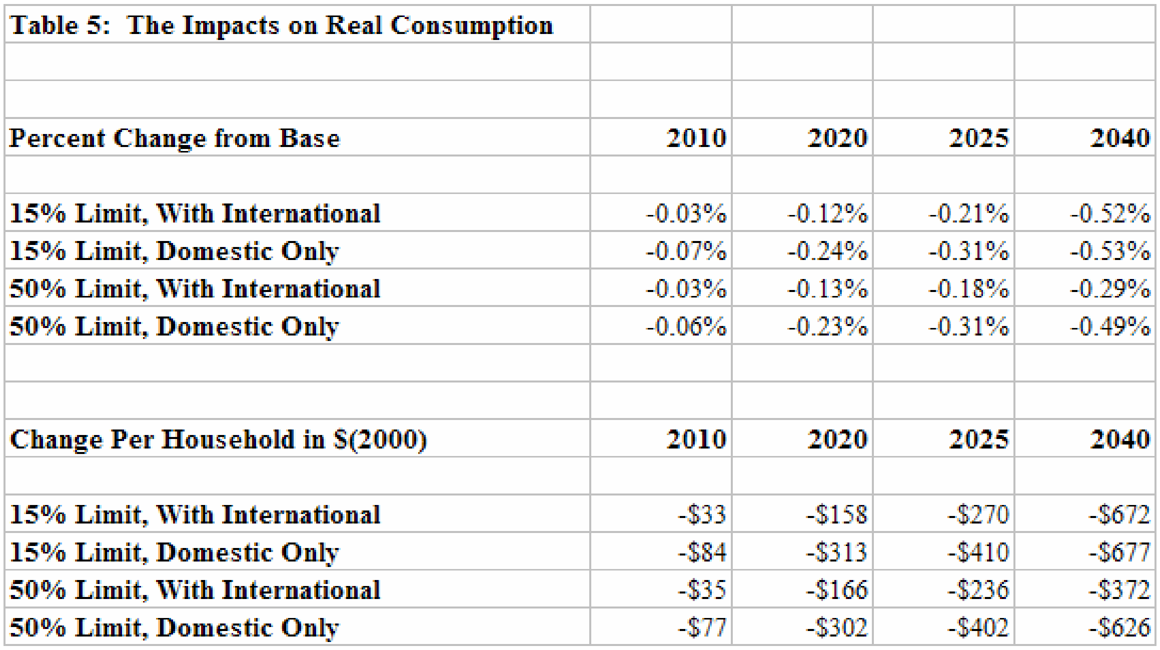


Table 5: The Impacts on Real Consumption				
Percent Change from Base	**2010**	**2020**	**2025**	**2040**
15% Limit, With International	-0.03%	-0.12%	-0.21%	-0.52%
15% Limit, Domestic Only	-0.07%	-0.24%	-0.31%	-0.53%
50% Limit, With International	-0.03%	-0.13%	-0.18%	-0.29%
50% Limit, Domestic Only	-0.06%	-0.23%	-0.31%	-0.49%
Change Per Household in $(2000)	**2010**	**2020**	**2025**	**2040**
15% Limit, With International	-$33	-$158	-$270	-$672
15% Limit, Domestic Only	-$84	-$313	-$410	-$677
50% Limit, With International	-$35	-$166	-$236	-$372
50% Limit, Domestic Only	-$77	-$302	-$402	-$626

A better perspective on the impact on consumers is provided by spending losses, in 2000 dollars, on a per household basis. By 2010, the average cost borne by an estimated 119 million households is around $35 when international permits are allowed and around $80 when only domestic offsets are allowed. By 2020, the average burden on the 134 million households rises to around $160 and $310, respectively. By 2040, the average cost per household range from $370 to $680 spread over 162 million households. The higher figures occur under the 15% limitations on offsets while the lower figures occur when these limitations are relaxed. As before, the smallest impact occurs when international permits are available under more generous allowances.

Traditionally, changes in GDP are viewed from the demand side as policies affect overall spending and its components. However, in CGE models, it is equally appropriate to focus on aggregate supply and, in particular, capital and labor inputs. Table 6 shows these for the four simulations. Like GDP and consumption, the capital stock and labor demand are less affected with international trading and with more relaxed constraints on the use of external offsets. As the 15% offset limit is reached, there is supply-side convergence reflected both in the accumulation of capital and in labor supply-demand equilibria. By 2040, the least favorable outcomes indicate declines in capital and labor availability of 1.4 and 0.8%, respectively. Under the most favorable conditions, these reductions are more than halved, to 0.6 and 0.3%, respectively.

Table 6: The Impacts on Capital and Labor				
Percent Change from Base				
Capital Stock	**2010**	**2020**	**2025**	**2040**
15% Limit, With International	-0.25%	-0.55%	-0.77%	-1.43%
15% Limit, Domestic Only	-0.45%	-0.75%	-0.89%	-1.44%
50% Limit, With International	-0.21%	-0.39%	-0.47%	-0.62%
50% Limit, Domestic Only	-0.43%	-0.73%	-0.86%	-1.18%
Labor Demand and Supply	**2010**	**2020**	**2025**	**2040**
15% Limit, With International	-0.20%	-0.41%	-0.53%	-0.79%
15% Limit, Domestic Only	-0.38%	-0.48%	-0.53%	-0.81%
50% Limit, With International	-0.17%	-0.25%	-0.26%	-0.27%
50% Limit, Domestic Only	-0.37%	-0.48%	-0.51%	-0.58%
Leisure Demand	**2010**	**2020**	**2025**	**2040**
15% Limit, With International	0.07%	0.14%	0.17%	0.26%
15% Limit, Domestic Only	0.13%	0.16%	0.17%	0.27%
50% Limit, With International	0.06%	0.08%	0.08%	0.09%
50% Limit, Domestic Only	0.13%	0.16%	0.17%	0.19%

5. Economic mechanisms

The consequences for the economy are more closely examined by considering the detailed adjustments in a particular year, 2020. These adjustments are representative of what happens in other years and in other simulations; the observed changes are matters of degree and not mechanisms. As shown in Table 7, the emissions constraint and resulting permit prices adversely affect each aspect of aggregate demand (real GDP) – consumption, investment, government purchases, exports and imports. Why does this occur? Simply put, everything becomes more expensive and everyone then must adjust to these higher prices. However, the mechanisms that give rise to these reactions are more numerous and complex.

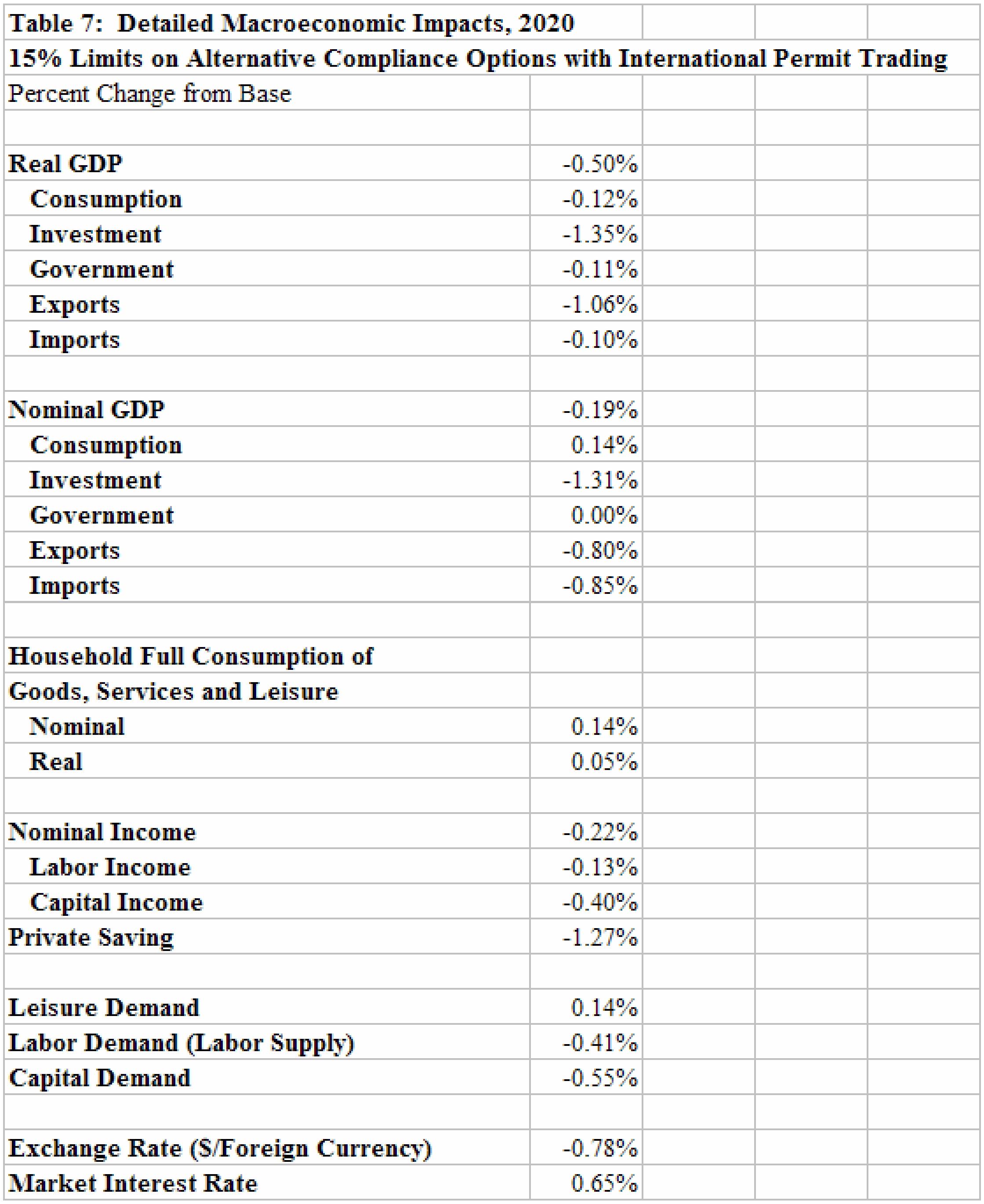


Table 7: Detailed Macroeconomic Impacts, 2020

15% Limits on Alternative Compliance Options with International Permit Trading

Percent Change from Base	
Real GDP	-0.50%
Consumption	-0.12%
Investment	-1.35%
Government	-0.11%
Exports	-1.06%
Imports	-0.10%
Nominal GDP	-0.19%
Consumption	0.14%
Investment	-1.31%
Government	0.00%
Exports	-0.80%
Imports	-0.85%
Household Full Consumption of Goods, Services and Leisure	
Nominal	0.14%
Real	0.05%
Nominal Income	-0.22%
Labor Income	-0.13%
Capital Income	-0.40%
Private Saving	-1.27%
Leisure Demand	0.14%
Labor Demand (Labor Supply)	-0.41%
Capital Demand	-0.55%
Exchange Rate ($/Foreign Currency)	-0.78%
Market Interest Rate	0.65%

The impacts on prices are presented in Figure 4. Clearly, energy prices – coal, oil, gas and electricity – are most affected, with coal more so than any other commodity. This is not surprising in that 90% of the year 2000 covered emissions are related to the use of coal (35%), oil (39%) and gas (16%). In addition, coal has a high carbon content in relation to the other fossil fuels and is used extensively along with oil and gas in the manufacture of electricity. Domestic crude oil and gas extraction prices decline under the condition in IGEM that approximates an upward sloping oil and gas supply curve. Here, the lower domestic production that follows from reduced demand is obtained at lower cost. This is the only price reduction that occurs. All non-energy prices increase. Some – chemicals, stone, clay and glass, primary metals, electrical machinery (semiconductors) and services (waste management) – are affected both directly and indirectly as their emissions are "covered" by the scenario examined. Others like agriculture, food, paper, plastics, motor vehicles, trade and finance are affected only indirectly.

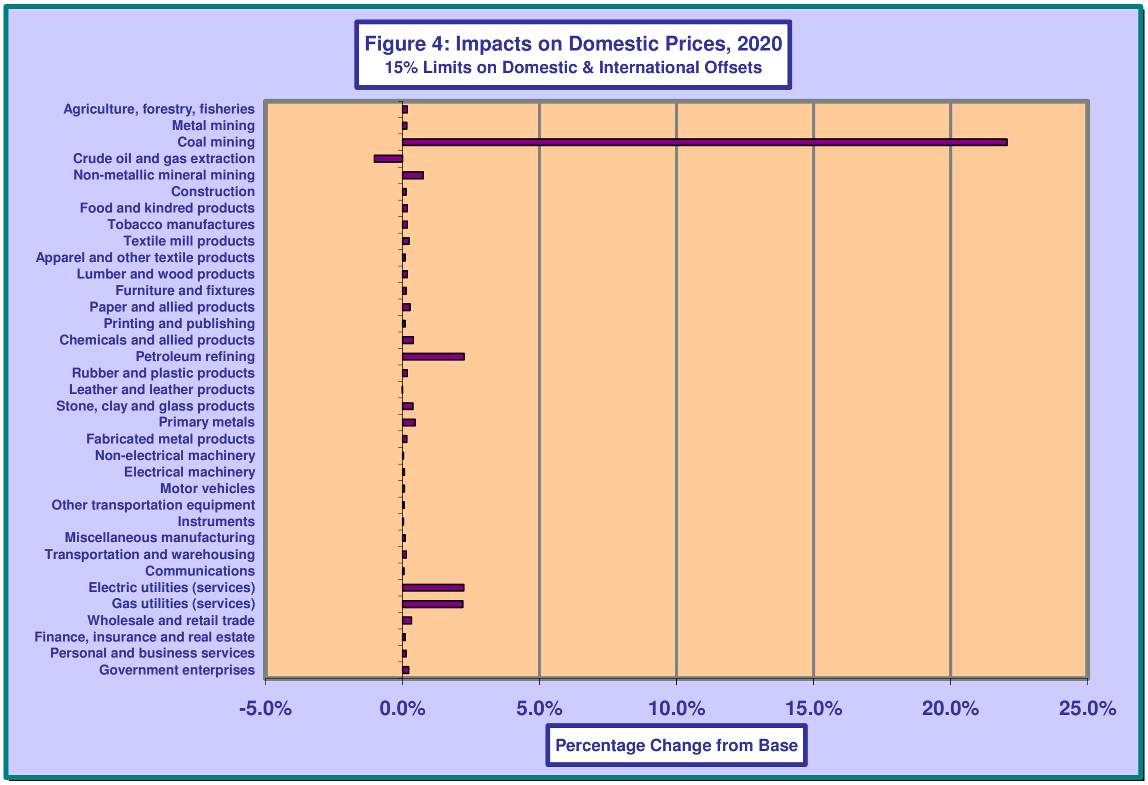


Figure 4: Impacts on Domestic Prices, 2020
15% Limits on Domestic & International Offsets

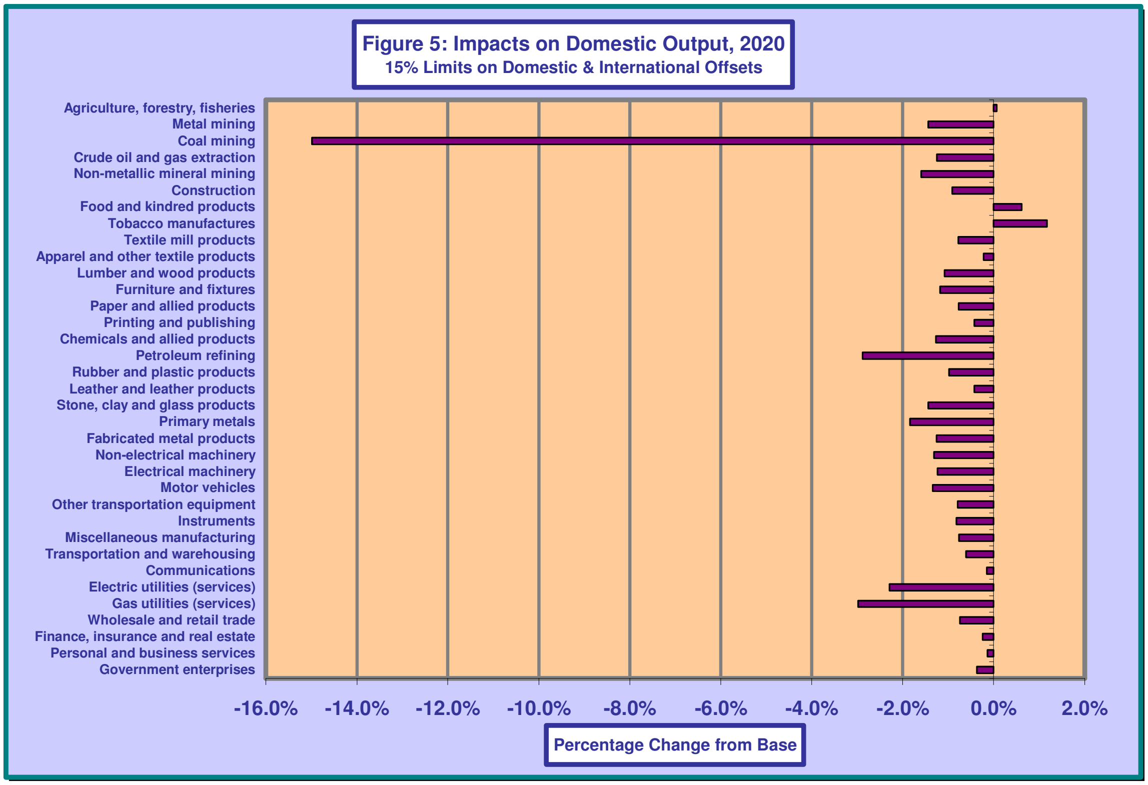
The overall impacts on the economy are dominated by the decisions of households. Their first decision concerns the inter-temporal allocation of expenditure on good, services **and** leisure, or so-called full consumption. Households know that the price increases from mitigation policy will be larger "tomorrow" than they are "today" as the emissions from a growing economy make stabilization at year 2000 emission levels more difficult over time. Households view this as a progressive erosion of real incomes and purchasing power. Accordingly, there occurs a redistribution of expenditure on full consumption toward the present and away from the future. Put another way, households substitute present-day full consumption for the future consumption of goods, services and leisure; they spend “now” rather than “tomorrow.”

Households next decide on the allocation of full consumption between goods and services on the one hand and leisure on the other. Because mitigation policy makes all consumer goods and services more expensive, the overall price of consumption is now also higher. The increased price of consumption relative to the price of leisure prompts households to substitute the latter for the former. Within the overall increase in full consumption arising from the inter-temporal effect, comparatively more is spent on leisure than is spent on consumer goods and services. The decline in real consumption occurs because the increase in consumer spending is proportionally smaller than the increase in consumer prices.

In addition to the consumption-related impact on aggregate demand, this second decision by households has important implications for the supply side of the economy. The rising price of goods and services relative to wages results in a reduction in household labor supply that is equal to and opposite from the increase in household leisure demand. Households respond to the decrease in real wages by supplying less labor and demanding more leisure. While increasing leisure is welfare improving for households, their reductions in labor supply, at prevailing wages, reduce labor and, hence, national income (GDP).

The third decision by households concerns the allocation of purchases among the variety of consumer goods and services but within the overall level of reduced total real spending. Like the adjustments above, there occurs here a redirection of expenditure away from those goods and services incurring the larger price increases and toward those goods and services experiencing the smaller price increases. Because household spending is such a large fraction of overall spending, the actions taken here strongly influence the structure of real GDP and the domestic production that supports it.

The production side of the economy also is affected adversely. With the exception of agriculture, food and related activities, all industries, especially those related to energy, experience declines in output volumes (see Figure 5). This results from not only higher prices and declining demands throughout the economy but also from the limitations on supply that arise from changes in labor and capital availability and from productivity. Producers do their best to insulate their output prices from the impacts of more expensive energy and non-energy inputs to production. Substitutions away from more costly inputs and toward relatively cheaper materials, labor and capital help minimize the adverse effects. Beyond these factor substitutions, there is also price-induced technical change (discussed in detail in Section 7) at work in each industry. This also affects output prices. The observed patterns of induced technical change unique to this policy are seen to help some industries but harm others. For some industries, induced technical change enhances the price-insulating benefits of factor substitution while, for other industries, it diminishes them. Overall, there is a small economic benefit from this mechanism as it reduces the economic costs of adjusting to the emissions of constraint. Ultimately though, there is only so much producers can do in the face of reduced demands and limited factor supplies. In the end, firm and industry profits and cash flows (i.e., the returns on invested capital) are unavoidably less.



The reduction in labor income arising from the household sector’s reduced labor supply and increasing demand for leisure combines with lower capital income from businesses to yield a reduction in national income and nominal GDP. However, as indicated above, personal consumption increases. In part, this is due to the inter-temporal effect of shifting spending from the future to the present. It is also due to the fact that overall consumption is price inelastic. This means that the proportionate reduction in real consumer purchases is smaller than the proportionate increase in the overall price of consumer goods and services. With falling income and rising consumption, private saving falls unambiguously. The reduction in saving leads to a corresponding reduction in private investment. With higher prices for investment goods, the available investment funding buys even fewer capital goods. Lower saving leads to lower investment, a lower capital stock, lower returns on that capital stock and less capital availability. This and the reduced availability of labor are primarily what limit the economy’s domestic supply possibilities following the introduction of this policy.

IGEM's saving-investment balance (see Appendix C) summarizes the net flow of funds available for investment. These funds arise from three sources. The first source, discussed above, is the domestic saving of households and businesses. All things being equal, increases in saving lead to more investment while decreases in saving lead to less. The second source reflects the behavior of the collection of governments that comprise the national economy and the magnitude of their combined annual deficit or surplus. The third source focuses on the nation's interactions with the rest of the world and whether the annual current account balance is deficit or surplus.

To eliminate governments' direct effects on real investment spending through the saving-investment balance, the simulations conducted for this analysis assume not only deficit but also revenue neutrality. Given these conditions of neutrality, as the prices facing governments rise, there occurs a proportionally equal reduction in the real goods and services that governments are able to purchase. While there are numerous reactions concerning the fiscal policies of governments, each with their own implications for spending, deficits and, hence, investment, the above assumptions give rise to transparent outcomes that are uncomplicated by speculations on what governments might do to soften any adverse policy impacts.

The prices of U.S. exports rise relative to goods and services from the rest of the world. As exports are estimated to be price-elastic, export volumes fall by proportionally more than export prices rise. In addition, there are no assumed policy-induced income effects associated with exports and, so, with only the aforementioned price effects, U.S. export earnings decline.

Real and nominal imports also decline. First, import reductions occur from the overall reductions in spending associated with a smaller economy. Second, import reductions occur in those commodities directly affected by mitigation policy. The cap on emissions and the corresponding emissions permits fall on all of the commodities that contribute to U.S. greenhouse gases, irrespective of whether they were produced domestically or imported. Thus, within total imports, there are disproportionate reductions in oil, gas and other policy-sensitive commodities as their prices rise along with those of their domestic counterparts. Finally, there is the matter of import substitution which partially offsets the above two forces. There is a greater incentive to import as domestic prices now are relatively higher for the commodities not directly affected by policy. For unaffected imports, there occurs a restructuring toward those commodities that obtain the greater price advantages in relation to those produced domestically and to those imports that are relatively cheaper within overall imports.

With only prices affecting exports and both prices and incomes affecting imports, the reduction in nominal imports exceeds the decline in export earnings. To neutralize this impact so that the effects on investment arise solely and transparently from those on domestic saving, the dollar strengthens to the point where it restores the current account balance to its pre-policy level. The condition in policy experiments that the value of the dollar adjusts to preserve existing (i.e., base case) current account balances (i.e., desired foreign saving) and U.S. indebtedness (i.e., willingness to hold dollar-denominated assets) is intentional in that IGEM is specified to represent only the domestic U.S. economy.

In the simulations in which there are no international permit purchases, current account balances and U.S. indebtedness to the rest of the world remain at their pre-policy levels. The adjustments in exports and imports, real and nominal, and in the value of the dollar are as just described. However, in the situations in which the U.S. purchases emissions permits from other Annex I countries, there occurs a presumed additional capital outflow as foreign investors are assumed to be less willing to maintain pre-policy U.S. asset levels. This capital outflow combines with the aforementioned domestic saving effect to further restrict domestic investment. In the case with 15% offset limits, this amounts to only a few percentage points of the total investment effect. In the case with 50% limits, the outflow effect is proportionally higher. The U.S. is purchasing even more foreign permits and the additional offsets explain much more of the overall investment effect. The purpose in making an assumption that is admittedly less favorable to domestic capital formation is to aid in establishing a plausible upper-bound estimate of the policy costs to the economy.

By way of sensitivity, changing export quantities and import prices to also reflect a plausible range of impacts from overseas emissions-reducing initiatives alters the magnitude of these export and import quantity changes. However, the changes in real net exports and GDP are not materially different from those reported above. They appear somewhat insensitive to the range of general equilibrium outcomes that were estimated for the policies of other nations and subsequently applied to IGEM's exogenous trade variables. Obviously, this experiment would benefit greatly from the use of detailed results, were such available, from world model policy simulations to better inform its conclusion.

6. Model comparisons

While a comparison of model differences, features, strengths and weaknesses lies well beyond the scope and purposes of this exercise, it is useful to put the aforementioned results in a perspective with other modeling efforts. To this end, key assumptions and outcomes from four additional assessments are compared, in Table 8, to those from DJA's IGEM. The other models are:

1. The Multi-region National and Multi-sector, Multi-region Trade (MRN & MS-MRT) Models of Charles River Associates (CRA).
2. The National Energy Modeling System (NEMS) of the U.S. Energy Information Administration (EIA).
3. The Emissions Projection and Policy Analysis (EPPA) Model of the Massachusetts Institute of Technology's (MIT's) Joint Program on the Science and Policy of Global Change.
4. The Applied Dynamic Analysis of the Global Economy (ADAGE) Model of the Research Triangle Institute International (RTI).

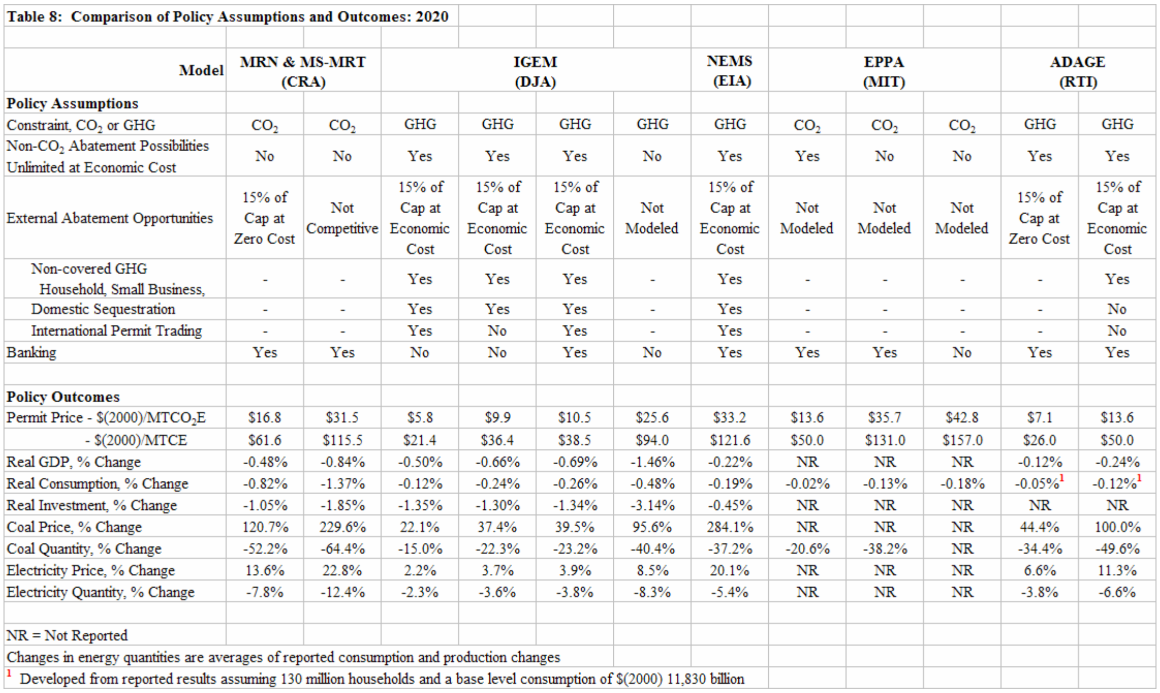


Table 8: Comparison of Policy Assumptions and Outcomes: 2020

Model	MRN & MS-MRT (CRA)		IGEM (DJA)				NEMS (EIA)	EPPA (MIT)			ADAGE (RTI)	
Policy Assumptions												
Constraint, CO_2 or GHG	CO_2	CO_2	GHG	GHG	GHG	GHG	GHG	CO_2	CO_2	CO_2	GHG	GHG
Non-CO_2 Abatement Possibilities Unlimited at Economic Cost	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes
External Abatement Opportunities	15% of Cap at Zero Cost	Not Competitive	15% of Cap at Economic Cost	15% of Cap at Economic Cost	15% of Cap at Economic Cost	Not Modeled	15% of Cap at Economic Cost	Not Modeled	Not Modeled	Not Modeled	15% of Cap at Zero Cost	15% of Cap at Economic Cost
Non-covered GHG Household, Small Business,	-	-	Yes	Yes	Yes	-	Yes	-	-	-	-	Yes
Domestic Sequestration	-	-	Yes	Yes	Yes	-	Yes	-	-	-	-	No
International Permit Trading	-	-	Yes	No	Yes	-	Yes	-	-	-	-	No
Banking	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes	No	Yes	Yes
Policy Outcomes												
Permit Price - $(2000)/MTCO$_2$E	$16.8	$31.5	$5.8	$9.9	$10.5	$25.6	$33.2	$13.6	$35.7	$42.8	$7.1	$13.6
- $(2000)/MTCE	$61.6	$115.5	$21.4	$36.4	$38.5	$94.0	$121.6	$50.0	$131.0	$157.0	$26.0	$50.0
Real GDP, % Change	-0.48%	-0.84%	-0.50%	-0.66%	-0.69%	-1.46%	-0.22%	NR	NR	NR	-0.12%	-0.24%
Real Consumption, % Change	-0.82%	-1.37%	-0.12%	-0.24%	-0.26%	-0.48%	-0.19%	-0.02%	-0.13%	-0.18%	-0.05%[1]	-0.12%[1]
Real Investment, % Change	-1.05%	-1.85%	-1.35%	-1.30%	-1.34%	-3.14%	-0.45%	NR	NR	NR	NR	NR
Coal Price, % Change	120.7%	229.6%	22.1%	37.4%	39.5%	95.6%	284.1%	NR	NR	NR	44.4%	100.0%
Coal Quantity, % Change	-52.2%	-64.4%	-15.0%	-22.3%	-23.2%	-40.4%	-37.2%	-20.6%	-38.2%	NR	-34.4%	-49.6%
Electricity Price, % Change	13.6%	22.8%	2.2%	3.7%	3.9%	8.5%	20.1%	NR	NR	NR	6.6%	11.3%
Electricity Quantity, % Change	-7.8%	-12.4%	-2.3%	-3.6%	-3.8%	-8.3%	-5.4%	NR	NR	NR	-3.8%	-6.6%

NR = Not Reported

Changes in energy quantities are averages of reported consumption and production changes

[1] Developed from reported results assuming 130 million households and a base level consumption of $(2000) 11,830 billion

The first three models have been used to analyze the Climate Stewardship Act proposed by Senators McCain and Lieberman. For comparison purposes, the IGEM-like ADAGE model utilized the same modest emission cap level as that proposed in the Climate Stewardship Act. Even with the same cap level, however, the results of all of these models vary widely because these models vary widely. IGEM is a general equilibrium model linked to the U.S. National Income and Product Accounts (NIPA). Its nested construction uses so-called flexible functional forms (i.e., functions with non-constant elasticities) that are econometrically estimated from the observed market behavior evidenced in the U.S. Accounts. The MRN & MS-MRT, EPPA and ADAGE models also are general equilibrium and linked to the social accounting matrices (SAMs) of their underlying nations and regions. These models are constructed with nested constant-elasticity-of-substitution (CES) functions populated with parameters from the extensive empirical literature and, in turn, calibrated to SAM benchmarks. Indeed, the EPPA and ADAGE models share a largely common parameter set. NEMS is an integrated, hierarchical system of partial equilibrium models linked to NIPA and to EIA's official U.S. Energy Accounts. The system combines econometrically-based, reduced-form (i.e., partial equilibrium) models of macroeconomic and energy-demand behavior with detailed process models related to energy production and supply. Dynamically, IGEM, the MRN & MS-MRT and ADAGE models feature inter-temporal optimization wherein economic agents are endowed with perfect foresight and make "current" consumption, leisure (labor) and saving (investment) decisions accordingly. The EPPA and NEMS models are dynamically recursive featuring current, within-period optimization based on knowledge only of the past and present.

The representations of various climate policy provisions within each model are also as varied as the models themselves. The IGEM, NEMS and ADAGE simulations involve caps on total greenhouse gas (GHG) emissions arising from "covered" activities whereas the MRN & MS-MRT and EPPA runs impose constraints on only carbon (CO_2) emissions. The IGEM, NEMS, EPPA and ADAGE analyses allow non-CO_2 abatement opportunities to compete at their economic cost; the MRN & MS-MRT simulations do not incorporate these. Only IGEM and NEMS consider the cost and availability of the full range of external offset opportunities. For the other models, the offsets from households, small businesses, domestic sequestration and international permit trading are not modeled, not competitive or compete at zero cost, the lone exception being the economic costs of household and small business offsets in the ADAGE model. Finally, only the IGEM and the EPPA runs permit a comparison of model outcomes with and without banking. Simulations from the other models all involve "optimal" banking in which permit prices rise at the prevailing interest rate throughout their reported time horizons.

In spite of the "apples-to-oranges" differences among these models and their policy assumptions, there are valuable insights to be gained from comparing their outcomes. First, when lower cost abatement options compete in the mix of market responses, the economic costs of mitigation, as measured by consumption or income (GDP), are reduced substantially. That the magnitude of cost reduction is so large, from 40 to 85% depending on the model and variable, testifies to the steepness of the marginal abatement cost schedules implicit in each of these methodologies. More or less the same abatement to reach 2000 emissions levels is very expensive. Thus, the combination of unlimited internal (non-CO_2) and-or limited external offsets, each at their lower cost, releases significant resources back to productive use that otherwise were diverted to compliance. Second, the economic costs of mitigation associated with a modest policy scenario are small; all models suggest that the economy easily absorbs initiatives of this magnitude. In terms of foregone consumption, the MRN & MS-MRT models yield the largest impacts while the EPPA and ADAGE models yield the smallest; the IGEM and NEMS outcomes lie in between. The similarity in the EPPA and ADAGE results is not surprising given the commonality of their structures and parameters. Moreover, as discussed in Section 8 below, a change in but a single IGEM parameter – that which governs the consumption-leisure tradeoff – reduces its losses to those levels among the lowest. Third, there is ample explicit (MRN & MS-MRT, IGEM and NEMS) and implicit (EPPA and ADAGE) evidence that the impacts of cap and trade policies on investment and capital formation significantly exceed those on consumption and household spending.

There are technical differences among these outcomes that, while of analytical interest, are somewhat less relevant to policy evaluation.[7] Broadly similar abatement requirements yield radically different patterns in permit prices and their associated impacts on energy and the economy. Indeed, all possibilities are represented. There are high permit prices showing relatively little economic effect (NEMS and EPPA), high permit prices showing the larger economic effects (MRN & MS-MRT), low permit prices showing the larger economic effects (IGEM as estimated) and low permit prices showing the smaller economic effects (ADAGE and the IGEM runs of Section 8). These patterns arise from the differing degrees of flexibility (i.e., elasticities) within the structures of these models. If emissions-generating goods and services are demanded inelastically, then permit prices need to be high to achieve their desired impact. Models with high permit prices imply models that are less elastic in energy prices (MRN & MS-MRT, NEMS and EPPA). The converse also is true (IGEM and ADAGE). In turn, if these changes interact less elastically with important segments of the larger economy, then

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[7] It is assumed that what really matters is achieving the desired emissions target with only minimal damage to the economy; all of the reported model runs generally satisfy this requirement.

responses at the “micro” level have less of an impact at the “macro” level. This explains, for example, why the higher permit prices in NEMS appear to have a disproportionately smaller impact on consumption than do the lower permit prices in IGEM.

A minor difference that surfaces in this comparison concerns the government and trade components of GDP. In the IGEM and NEMS simulations, adjustments in these complement the changes in consumption and investment, further reducing GDP. In the MRN & MS-MRT analysis, the reductions in GDP are proportionally smaller than both those of consumption and investment. This can occur only if the changes in real government spending and-or real net exports (i.e., exports less imports) partially offset the combined changes in household and business spending. While interesting, and presumably related more to trade than to changes in government behaviors, this difference merits explanation only in discussions of the impacts on overall spending (GDP) and income. As the principal evaluative metric for these assessments is consumption (household spending), this difference loses some of its relevance.

In the end, there is but one dominant conclusion from this cursory comparison – namely, that legitimate, verifiable and competitive market-based abatement opportunities can reduce significantly the already small economic costs of mitigation policy.

7. Induced technical change

Among the more widely discussed aspects of climate change and climate change policy is the role of induced technical change (ITC). It is likely that firms react to their new realities by unleashing a wave of R&D projects and input and output restructurings. The private and social returns on these investments and on the cumulative effects of learning-by-doing lead not only to lower emissions and emissions growth but also to reductions in their associated economic costs. As Goulder concludes in his 2004 Pew Center monograph on this subject, the presence of ITC lowers the economic costs of achieving a given target or, equivalently, allows more aggressive reductions for a given willingness-to-pay. While IGEM cannot distinguish the payoffs of R&D from those of learning-by-doing, it can provide a plausible estimate of the magnitude of ITC benefits.

It is important to note what IGEM can and cannot contribute to an analysis of ITC. IGEM is specified and estimated in a manner that isolates the portion of observed technical change that is the collective outcome of price-induced innovation within an industry (Appendix B and Jorgenson and Hui Jin, 2005 and 2006). Historically, productivity (i.e., technical change) is empirically biased, reflecting induced and systematic changes in the cost structure of inputs. These changes are independent of input prices. In simulation, IGEM combines the estimated patterns of induced innovation with evolving trends in relative prices. The end result is an estimate, unique to each scenario, of the rate, direction and magnitude of price-induced technical change. This estimate presumes that the ongoing historical patterns of induced innovation, which are invariant across scenarios, can fairly characterize those of the simulation period.

IGEM's representation of price-induced technical change is best viewed as a reasonable first approximation of this phenomenon. To fully model induced innovation requires, first, a well-accepted theoretical understanding of the process whereby price changes influence the directions of business innovation and, second, a corresponding empirical basis for the states of technology and the stocks of knowledge and their evolution at the firm-industry level. There is a growing theoretical literature in the areas of firm, industry and economy-wide ITC but there is very little in the way of empirical content to inform it. To remedy this, IGEM posits a theoretical structure of production and an associated methodology for its estimation. IGEM then is capable of portraying the temporal structure of industry innovation.

Under IGEM's specification, the levels of technology inherent in cost and production functions at a particular point in time are independent of the historical path of prices. Because of this, IGEM represents only a portion of ITC's full impact, namely, the portion due to observed changes in the levels and time paths of relative prices; missing are any potential changes in the innovation multipliers of these prices. Over the historical period

(1958-2000), IGEM's representation of induced innovation reflects what actually occurred and, when combined with actual historical price changes, yields the full measure of the effects of ITC. For the future, a policy change introduced into IGEM alters the patterns of relative prices and so "induces" changes in productivity, albeit, through policy-invariant patterns of innovation. The full measure of the effects of ITC in these cases depends on how well the continuing trends in observed innovation portray future realities. IGEM's portrayal of ITC is not a forecast of what will happen but, rather, a simulation of price-induced productivity change conditional on observed and prevailing behavior; it is a plausible and reasonable metric for comparative purposes.

To ascertain the importance of ITC in these results, two additional simulations are performed. These draw information from the base case and from the two policy cases in which there are 15% limits on the use of offsets. In each case, model results are used to calculate the magnitude of ITC within that simulation. Next, the differences between the policy cases and the base case are determined. These differences measure the changes in ITC that are themselves induced by the relative price changes in IGEM from one or the other of these policy variations. The two policy cases then are re-run, netting out or negating these differences. This is equivalent or nearly so to eliminating the impacts of *policy*-induced technical change from each of the model runs. This is also equivalent to locking the path of technical change from the base case simulation and comparing the locked version with the free version.

This "counterfactual" experiment yields the following findings. First, the economic costs of mitigation policy are lower with ITC than they are in its absence (see Table 9). The benefits of ITC are proportionally greater for consumption and the process of capital formation than they are for overall spending and income but, nevertheless, there are measurable benefits economy-wide. Indicative of robustness, the effects on consumption and the capital stock are virtually identical to the results from an earlier but slightly different model and experiment in which ITC was eliminated completely, not just negated (Jorgenson et al., 1993). This earlier approach had a potential disadvantage of comparative scale in that it required multiple base case simulations; the approach taken here avoids this by involving only a single base case.

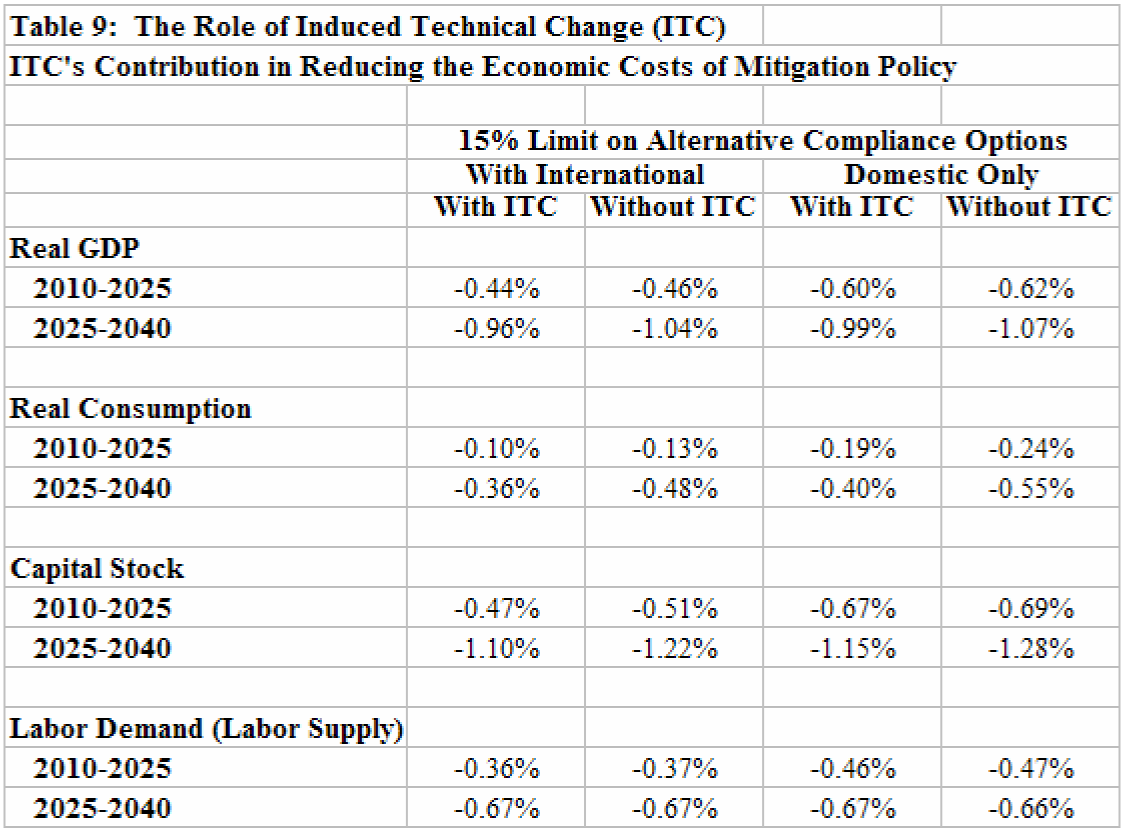

Table 9: The Role of Induced Technical Change (ITC)

ITC's Contribution in Reducing the Economic Costs of Mitigation Policy

	15% Limit on Alternative Compliance Options			
	With International		Domestic Only	
	With ITC	Without ITC	With ITC	Without ITC
Real GDP				
2010-2025	-0.44%	-0.46%	-0.60%	-0.62%
2025-2040	-0.96%	-1.04%	-0.99%	-1.07%
Real Consumption				
2010-2025	-0.10%	-0.13%	-0.19%	-0.24%
2025-2040	-0.36%	-0.48%	-0.40%	-0.55%
Capital Stock				
2010-2025	-0.47%	-0.51%	-0.67%	-0.69%
2025-2040	-1.10%	-1.22%	-1.15%	-1.28%
Labor Demand (Labor Supply)				
2010-2025	-0.36%	-0.37%	-0.46%	-0.47%
2025-2040	-0.67%	-0.67%	-0.67%	-0.66%

Second, the role of ITC is small in comparison to the much larger effects of substitution and economic restructuring (Jorgenson et al., 2000). Over the period 2025-2040, ITC reduces the cost of economic adjustment by 7 to 8% for GDP, by 9 to 10% for the capital stock and by 25 to 26% for household consumption. These relative magnitudes are consistent with findings summarized in the Pew Center report (Goulder, 2004) and with other informative contributions to the recent literature (Nordhaus, 2002 and Wing, 2003).

Finally, the favorable impacts of ITC are cumulative. From the onset, there are measurable and positive benefits and these increase with the passage of time. Again, these ITC effects arise solely from the interactions of the estimated factor biases and the policy induced changes in relative prices. There currently is little or no empirical basis for targeted adjustments in the biases themselves although Popp (2001 and 2002) and

Wing and Eckaus (2004) have taken important steps in this direction. If policy were to induce or, more importantly, if it also provided incentives designed to appropriately alter these biases (e.g., targeted R&D and investment tax credits), then these results would be magnified. The role of ITC would become vastly more significant reflecting the driving forces of not only relative price changes but also policy-induced innovation, reflected in non-price changes in factor intensities.

A secondary feature of these simulations, shown in Table 10, is that permit prices are marginally lower in the absence of ITC. The reasons for this are twofold and depend on the consequences, in general equilibrium, of ITC at the sector level and in aggregate (see Table 11). Eliminating the ITC effects that arise from a given policy has an overall negative effect on economic performance. As evidenced by the value-share weighted average of the ITC effects in each industry, the economy is smaller when these ITC effects are netted out of the simulation. As the economy is smaller, GHG emissions are lower and permit prices do not need to be as high to achieve the required abatement.

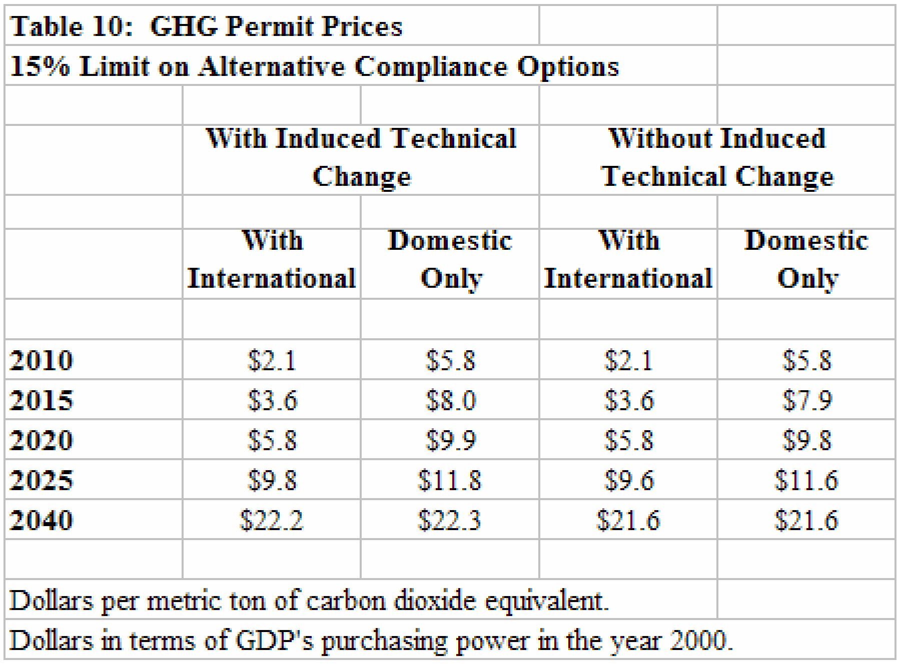

Table 10: GHG Permit Prices

15% Limit on Alternative Compliance Options

	With Induced Technical Change		**Without Induced Technical Change**	
	With International	**Domestic Only**	**With International**	**Domestic Only**
2010	$2.1	$5.8	$2.1	$5.8
2015	$3.6	$8.0	$3.6	$7.9
2020	$5.8	$9.9	$5.8	$9.8
2025	$9.8	$11.8	$9.6	$11.6
2040	$22.2	$22.3	$21.6	$21.6

Dollars per metric ton of carbon dioxide equivalent.

Dollars in terms of GDP's purchasing power in the year 2000.

Table 11: Induced Technical Change at the Interindustry Level, 2020

15% Limit on Alternative Compliance Options, Domestic Only

Percent Change from Base

	ITC Effects	
Industry	**Absolute Level**	**Relative Contribution**
Electric utilities	-1.864%	-0.042%
Crude oil and gas extraction	-0.828%	-0.016%
Motor vehicles	-0.475%	-0.009%
Chemicals and allied products	-0.214%	-0.007%
Non-electrical machinery	-0.090%	-0.005%
Printing and publishing	-0.183%	-0.004%
Petroleum refining	-0.118%	-0.003%
Food and kindred products	-0.118%	-0.003%
Lumber and wood products	-0.401%	-0.003%
Rubber and plastic products	-0.187%	-0.002%
Apparel and other textile products	-0.132%	-0.002%
Electrical machinery	-0.037%	-0.002%
Transportation and warehousing	-0.052%	-0.002%
Textile mill products	-0.151%	-0.001%
Stone, clay and glass products	-0.166%	-0.001%
Finance, insurance and real estate	-0.008%	-0.001%
Communications	-0.031%	-0.001%
Other transportation equipment	-0.028%	0.000%
Furniture and fixtures	-0.047%	0.000%
Tobacco manufactures	-0.290%	0.000%
Metal mining	-0.067%	0.000%
Non-metallic mineral mining	0.016%	0.000%
Leather and leather products	0.052%	0.000%
Miscellaneous manufacturing	0.023%	0.000%
Paper and allied products	0.020%	0.000%
Fabricated metal products	0.077%	0.001%
Government enterprises	0.142%	0.002%
Coal mining	1.062%	0.004%
Gas utilities	0.197%	0.004%
Instruments	0.299%	0.004%
Agriculture, forestry, fisheries	0.191%	0.004%
Primary metals	0.313%	0.005%
Wholesale and retail trade	0.066%	0.009%
Personal and business services	0.084%	0.013%
Construction	0.205%	0.014%
Value-share weighted average	**-0.046%**	**-0.046%**

Notes:

Negative numbers indicate that ITC is working to lower prices. Eliminating this impact harms this industry and the overall economy.

Positive numbers indicate that ITC is working to raise prices. Eliminating this impact helps this industry and the overall economy.

In combination, eliminating these effects harms the overall economy as indicated by the negative overall average.

Eliminating these ITC effects also has structural implications for the economy and, so too, for energy use and GHG emissions. This is illustrated by focusing on three sectors in Table 11 – electric utilities, trade and services. ITC in the electric utilities sector plays the dominant role in the overall ITC effect observed for this policy. In the presence of ITC, this means that electricity prices are lower and demand is higher than would be the case were there to be no ITC. In short, the empirically observed ITC in this sector works somewhat against the goals of this policy. Since ITC helps to lower electricity prices, unconstrained energy use and emissions are higher which means that permit prices also have to be higher to achieve a given emissions reduction. However, in the absence of ITC, electricity prices are higher and demand is lower. These imply a corresponding reduction in energy inputs to this sector and, hence, lower emissions. The absence of ITC in the electricity sector reduces the electricity intensity of the economy which means that permit prices do not have to rise as high to satisfy the emissions constraint.

ITC in trade and services have different implications but contribute similarly to this outcome. The ITC effects calculated for these sectors work to raise their prices. This is harmful to their growth and to the overall economy. Eliminating these ITC effects lowers the relative prices of trade and services, improves their relative performance and helps the economy. But these sectors are not energy or emissions intensive. The restructuring that occurs in the absence of these calculated ITC effects yields an economy that is less energy and emissions intensive and, again, the permit prices that are necessary to achieve the targeted reduction are marginally lower.

8. Consumption and leisure choices

As demonstrated in the Pew Center report on substitution (Jorgenson et al., 2000), the parameter governing the allocation of full consumption between the demand for goods and services (i.e., consumption) and the demand for leisure is a dominant factor in model outcomes. There it was shown that making the consumption-leisure choice less elastic substantially reduced the economic costs of mitigation policy. The GDP and investment effects were more than halved and the impacts on household welfare, consumption and leisure were all but eliminated. In addition, rigidity in the desired consumption-leisure tradeoff removed any possibility of a “double dividend” from the more economically beneficial recycling of permit revenues.

That this parameter plays so dominant a role is not surprising. In that there is a fixed amount of discretionary time to allocate between work and leisure, household choices concerning leisure demand simultaneously determine labor supply and, hence, labor income; in IGEM, as in most CGE models, labor supply is the complement of leisure demand and there is no “unemployment” gap between the quality-adjusted hours offered by households and those demanded by employers. Also, for a given national income, decisions on how much to consume determine the household and business saving that funds private investment. Investment adds to the capital stock which, in turn, is the source of capital income. From these, it is evident that this single decision influences the entire supply side of the economy.

The practice of adopting parameters from the empirical literature is the norm in constructing CGE models (e.g., RTI, 2005). For labor supply, this poses a significant aggregation problem (Fullerton and Metcalf, 2001). Many studies focus their attention on the labor supply decisions of various demographic cohorts (defined by sex, age, race, occupation, industry, etc.) who are already employed. The goal here is to ascertain a willingness to supply additional hours in response to changes in real wages. Unfortunately, these studies do not simultaneously consider labor force participation, a topic with an equally broad and diverse literature. Developing a single parameter for a representative household requires aggregating both within and across these two very distinct sets of literature. RTI and Fullerton and Metcalf reference Russek (1996) who attempts just such an aggregation. Piecing together the details of the Russek article, Fullerton and Metcalf reveal a possible range of 0.1 to 0.6 for the compensated elasticity of labor supply. A consumption-leisure parameter leading to a labor supply elasticity that falls within this range is common among CGE models. For example, the ADAGE model of RTI uses 0.35 as its estimate of the compensated labor supply elasticity.

The consumption-leisure parameter is but part of IGEM's comprehensive model of household behavior and is econometrically estimated from long-run historical data. Over various vintages of the model, estimation has yielded higher elasticity figures than those obtained from aggregation schemes. The disparities between IGEM and other top-down estimates of labor's responsiveness and those from bottom-up aggregations have yet to be reconciled in the literature. More relevant to this effort is the fact that IGEM's more elastic labor-leisure response is a driving force underlying the economic costs of GHG abatement.

The time-varying compensated elasticities of labor supply computed in IGEM simulations range from just over 0.8 to just under 1.0. This is more elastic than the bottom-up estimates adopted for other models but is still inelastic. To see the impact of this parameter, three additional simulations are performed. First, the parameter affecting the consumption-leisure tradeoff is set to yield a compensated elasticity of labor supply that averages around 0.3 over the period of simulation. A new base case then is created and proportionally identical policy runs are analyzed for the two cases involving 15% limits on offsets.

Not unexpectedly, making consumption and leisure less elastic (leading to decreases in the responsiveness of labor supply from 0.8 to 0.3) substantially reduces the economic costs associated with cap and trade policies. Figure 6 compares the impacts on GDP of more and less relative responsiveness. Table 12 similarly compares the impacts on consumption, capital formation, labor supply and leisure demand. In each case, the consequences for the economy are substantially smaller when the desired household substitutions between consumption and leisure are less. With less elastic consumption-leisure, the longer run impacts on GDP and capital are only 70 to 75% as large as with more elastic demands. Labor and leisure effects are just over 50% as large and the consumption impact is less than 30% as large.

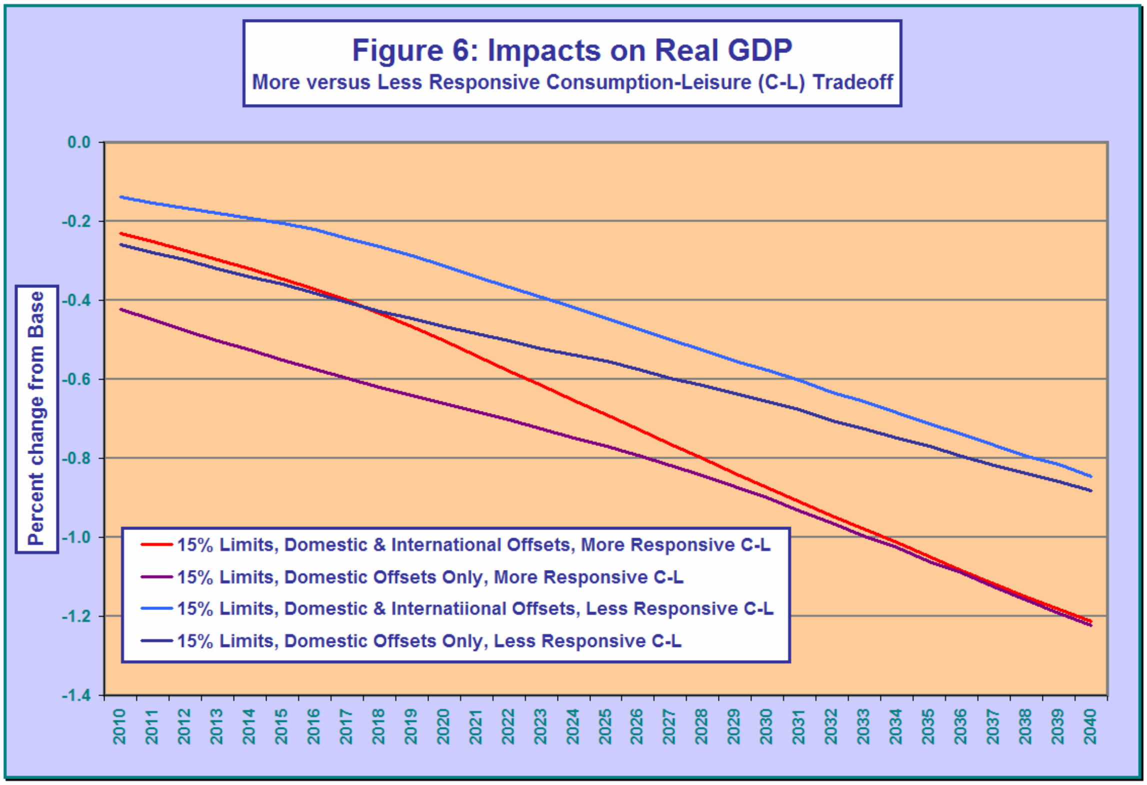

Figure 6: Impacts on Real GDP

More versus Less Responsive Consumption-Leisure (C-L) Tradeoff

Table 12: Price Responsiveness in Household Consumption-Leisure Decisions

15% Limit on Alternative Compliance Options

	More Responsive (IGEM as estimated)		**Less Responsive (IGEM constrained)**	
	With International	**Domestic Only**	**With International**	**Domestic Only**
Real Consumption				
2010-2025	-0.10%	-0.19%	0.00%	-0.02%
2025-2040	-0.36%	-0.40%	-0.07%	-0.12%
Capital Stock				
2010-2025	-0.47%	-0.67%	-0.30%	-0.47%
2025-2040	-1.10%	-1.15%	-0.78%	-0.90%
Labor Demand (Labor Supply)				
2010-2025	-0.36%	-0.46%	-0.20%	-0.30%
2025-2040	-0.67%	-0.67%	-0.38%	-0.35%
Leisure Demand				
2010-2025	0.12%	0.15%	0.06%	0.09%
2025-2040	0.22%	0.22%	0.12%	0.11%

These are very dramatic effects from a single parameter with, unfortunately, little or no basis for distinction beyond expert opinions or one's personal beliefs. A new econometric effort, rich in demographic detail, from Jorgenson and Slesnick (2005) involves four top-tier components of household expenditure – non-durables, capital services, consumer services and leisure. The compensated elasticity of labor supply derived from these estimates is 0.7 and leisure demand is determined to be income (expenditure) elastic. Given the nature and magnitude of inter-temporal substitutions, these favor the more elastic results from IGEM. However, the uncompensated elasticity of labor supply is virtually zero. This favors the less elastic results from IGEM. Until these differences are reconciled yielding a definitive consensus, the analytical community and its audience do best to rely on a bounded range of outcomes such as offered here.

9. Longer-term considerations: Banking and Beyond 2020

There are two remaining issues that relate to economic costs over the intermediate and long run. The first of these is banking which typically is not considered a long-run issue but has the potential for being so. The second concerns the cap and trade policy beyond 2020. To simplify analysis and to better focus on matters most relevant, the simulations examined in this section allow all competing offsets – those from households and small businesses, domestic sequestration and from international markets; there are no runs involving only domestic offsets. However, there continues the distinction between 15% and 50% limits on the use of these.

a. Banking

Most of the climate change legislation being discussed allows unlimited banking. When banking occurs, covered sources more than meet their compliance targets in earlier years. They then bank permits for future use when marginal abatement costs are much higher and required emissions reductions are more difficult. Banking, therefore, is equivalent to imposing a tighter emissions constraint initially and a looser one later. Effective permit prices with banking are initially higher than those without banking. Eventually, they give way to prices lower than those without banking. With banking, there are more economic resources reallocated to abatement activities in the earlier years but fewer in the later years. An efficiency gain is realized as the present value of the greater nearer-term costs is more than compensated by the present value of longer-term savings.

Assuming the right to bank is permitted throughout a policy's time horizon, the driving force in modeling the banking decision is the market rate of interest, reflecting, as it does, opportunity cost and the time value of money. If the annual rate of change in permit prices is lower than the rate of interest, there is no incentive to bank permits for future use. However, if the annual rate of change in permit prices exceeds the market interest rate, there is an arbitrage opportunity that can be seized by banking permits.

For a given interest rate and assuming inter-period trading on a one-for-one basis, optimal banking is an analytical problem with two jointly determined unknowns. The first is the initial permit price which then rises annually with prevailing interest rates. The second is the year in which the permit price is high enough to equate annual permit demand with new permit issues while simultaneously exhausting the supply of banked permits. Lower interest rates encourage more banking over a longer time horizon. Compared with no banking, permit prices and economic costs are higher earlier but lower later. Higher market rates reduce the incentives for banking and shorten its window of opportunity. Higher interest rates tilt the rewards and penalties of banking toward those of not banking. In the limit, any incentive for banking is eliminated.

As IGEM tracks to a zero-growth, steady-state solution, there is convergence among the market rate of interest, the marginal physical product of capital and the household rate of time preference. This is a predicted outcome of economic growth theory. In IGEM, the market interest rate is a model output, not a model input. At the onset of policy, the simulated rate stands in the neighborhood of 3.2% and then gradually declines toward 2.6%, the econometrically estimated rate of time preference.

Assuming no banking and a 15% limit on offsets, the market-clearing permit price increases at a slowly decreasing rate as the economy evolves toward its post-2060 steady state. Under these conditions, the annual rate of increase exceeds the market interest rate until mid-century. Thus, there is a strong incentive for banking over an extended time horizon.

Figure 7 shows the trajectory of permit prices with and without banking while Figure 8 depicts the accumulation and drawdown of banked permits. The crossover year for permit prices is 2032. The stock of unused permits peaks in 2029. For the economy, the crossover year also is 2032. As productive inputs are redirected to abatement activities prior to 2032 and are released from same after 2032, the economic costs in terms of income and consumption foregone are greater in the earlier years and smaller in the later years.

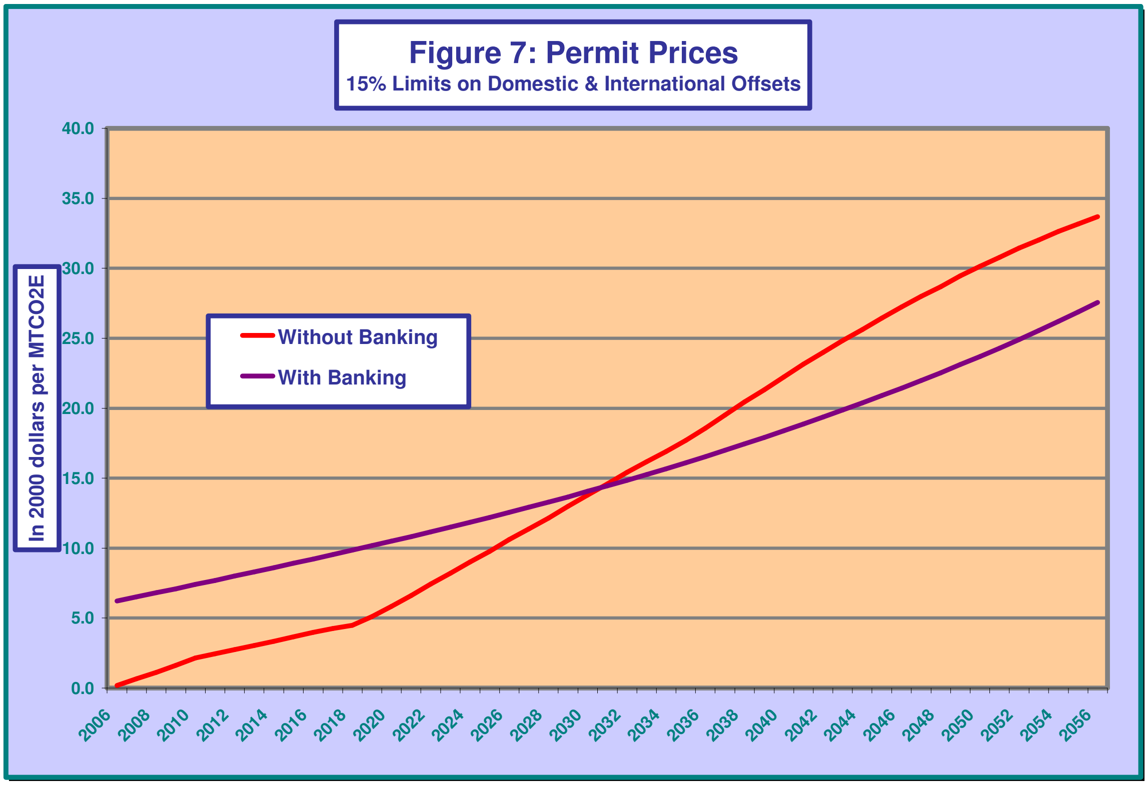

Figure 7: Permit Prices

15% Limits on Domestic & International Offsets

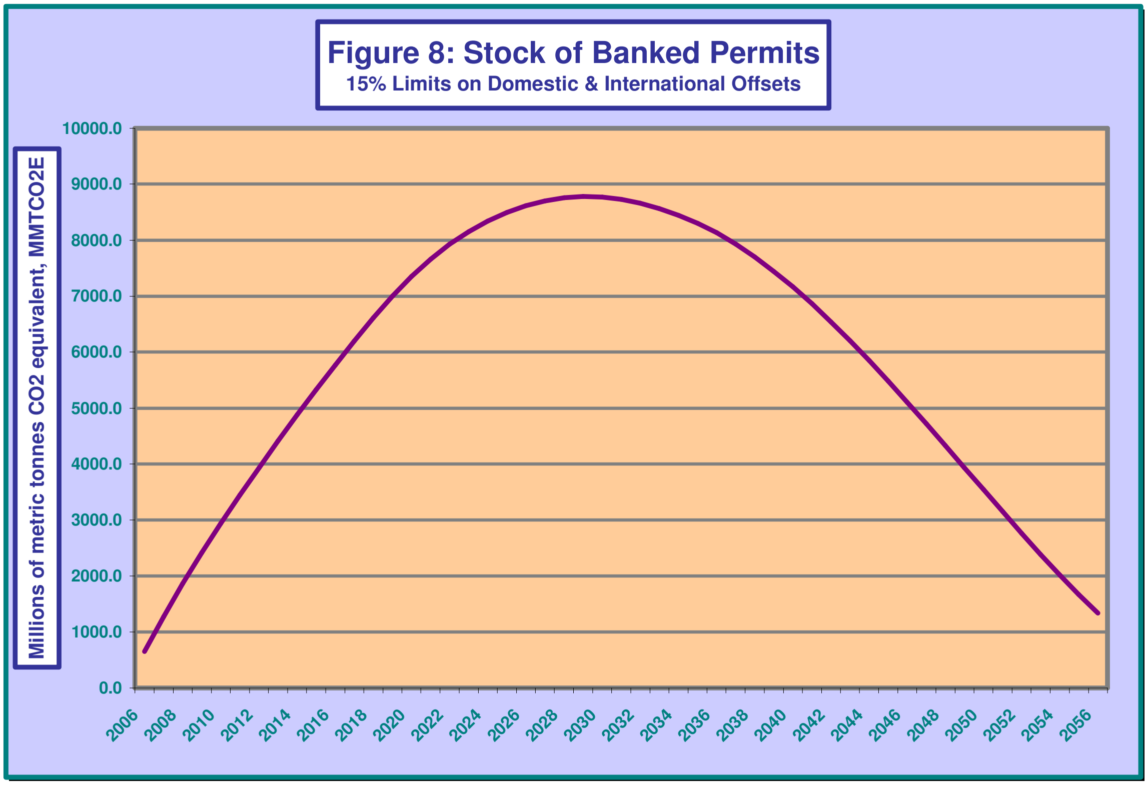

Figure 8: Stock of Banked Permits

15% Limits on Domestic & International Offsets

For GDP, the incremental cost associated with banking averages 0.2 percentage points, 2010-2025 (see Figure 9). There is virtually no cost differential, 2025-2040. From 2040-2060, the gain or benefit from banking averages 0.1 percentage points and is half again as much in steady state. For consumers, banking costs a extra $94 per household in 2010 and an extra $198 by 2020. Thereafter, these additional costs diminish rapidly becoming gains of $18 in 2040, $62 in 2060 and $110 in steady state.

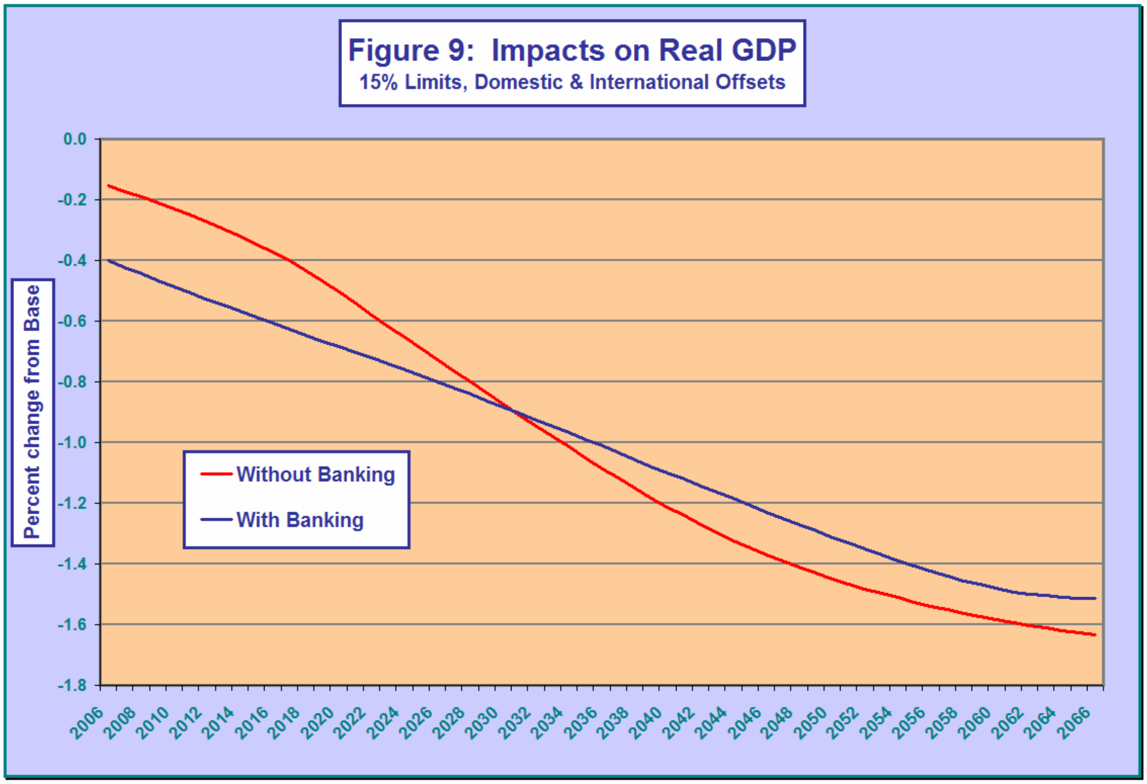
Figure 9: Impacts on Real GDP
15% Limits, Domestic & International Offsets

Real-world uncertainties aside, the amount of banking and its economic impact in model simulations depend on the time paths of evolving permit prices and prevailing interest rates. If real interest rates are in the range of these in IGEM, optimal banking is a long-run proposition. Here, economic efficiency warrants incurring higher costs for multiple decades, not just multiple years. In these circumstances, achieving a net benefit requires endurance and patience.[8] Conversely, higher rates, like the 5% rate employed by CRA and MIT and the 8.5% rate used by EIA, bring about lesser amounts of banking and shorten the period over which it is desirable. In turn, these will lower banking's nearer-term losses and raise its longer term gains, increasing the immediacy of an overall net benefit. Understanding how quickly a net benefit from banking materializes under various schemes of permit prices and interest rates is an important consideration in the analysis of mitigation policy.

b. Emissions policy after 2020

The scenarios evaluated in this report can be thought of as modest first steps toward discouraging future emissions growth. Accordingly, all of the simulations to this point maintain the cap at 2000 levels indefinitely. This section provides estimates of the economic costs of more restrictive emissions ceilings beginning in 2020.[9] Specifically, two additional constraints, shown graphically in Figure 10, are analyzed.[10] In the first, the cap is reduced annually by 0.5% and, in the second, allowable emissions in the covered sectors decline by 1.0% per year. In the former, emissions reach 1990 levels of 5121 $MMTCO_2E$ by 2050 while, in the latter, this level is achieved by 2035. Relative to the base case level in 2040, the simulations to this point involved an emissions reduction of 31.8% or 2768 $MMTCO_2E$. Here, the corresponding figures are 38.3% (3334 $MMTCO_2E$) and 44.2% (3849 $MMTCO_2E$) for the 0.5% and 1.0% constraints, respectively.

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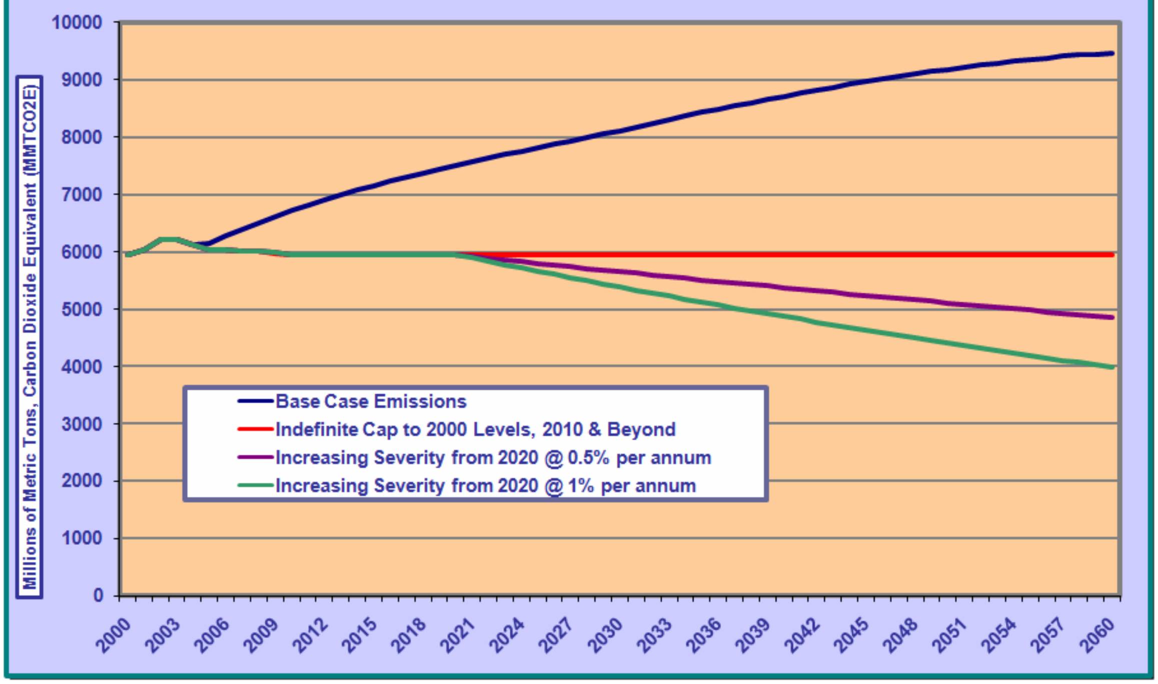
[8] That the later gains from banking do not appear to compensate the earlier economic losses is an artificial result. Were the proximity of steady state more distant from the crossover point, the discounted benefits from banking would continue to expand and, ultimately, outweigh the earlier discounted costs.

[9] A variety of climate change bills have been introduced in the 110th Congress that require more restrictive emissions reductions over time.

[10] The more restrictive emissions ceilings are arbitrary and intended purely to measure the impacts of further reductions beyond 2020; neither scenario has been considered in any formal policy proposal or deemed optimal in any formal modeling exercise.

Figure 10: GHG Emissions, Covered Sectors



The 15% and 50% limitations on offsets remain and it is assumed that all domestic and international offsets are available at their economic cost. However, there is one difference. In these simulations, the limits on offsets follow the cap. As allowable emissions become further restricted so, too, does the ability to use external offsets. After 2020, the 892 and 2974 MMTCO$_2$E limits in the 15 and 50% cases, respectively, also decline at the annual rates of 0.5 and 1% depending on the scenario.

Table 13 compares the permit prices under the various caps. Prior to 2020, there are virtually no differences among the permit prices for comparable limitations on alternative offsets. This is to be expected since the more restrictive emissions ceilings do not take effect until 2021 which is when prices begin to diverge. By 2040 and with a 15% limit on offsets, permit prices rise by $14 and $18 per MTCO$_2$E as the cap is successively reduced. Under the 50% limit with the significantly lower permit prices from more generous offsets, the successive increases rise to $16 and $20 per MTCO$_2$E. Ratcheting down the target on allowable GHG emissions clearly imposes additional costs on the economy no matter what the offset policy.

Table 13: GHG Permit Prices under Alternative Caps Post-2020			
	15% Limit on Alternative Compliance Options		
	2000 Levels Indefinitely	**0.5% Annual**	**1.0% Annual**
2010	$2.1	$2.1	$2.1
2015	$3.7	$3.6	$3.6
2020	$5.9	$5.8	$5.7
2025	$9.8	$11.9	$14.2
2040	$22.3	$36.7	$54.3
	50% Limit on Alternative Compliance Options		
	2000 Levels Indefinitely	**0.5% Annual Reduction**	**1.0% Annual Reduction**
2010	$2.1	$2.1	$2.1
2015	$3.7	$3.6	$3.6
2020	$5.1	$5.0	$4.9
2025	$6.1	$9.5	$12.9
2040	$8.7	$24.6	$44.4
Dollars per metric ton of carbon dioxide equivalent.			
Dollars in terms of GDP's purchasing power in the year 2000.			
Alternative compliance options at zero cost.			

Figures 11 and 12 show the effects of more restrictive caps on real GDP and consumption, respectively. The differences among these time paths prior to 2020, more pronounced for GDP than for consumption, are evidence of IGEM's inter-temporal effects and their general equilibrium aftermath. Some of the adjustment in the driving forces of supply and demand in these earlier years is related to knowledge of the future evolution of permit prices beyond 2020. Greater economic costs in the future often trace backward to greater economic costs nearer term.

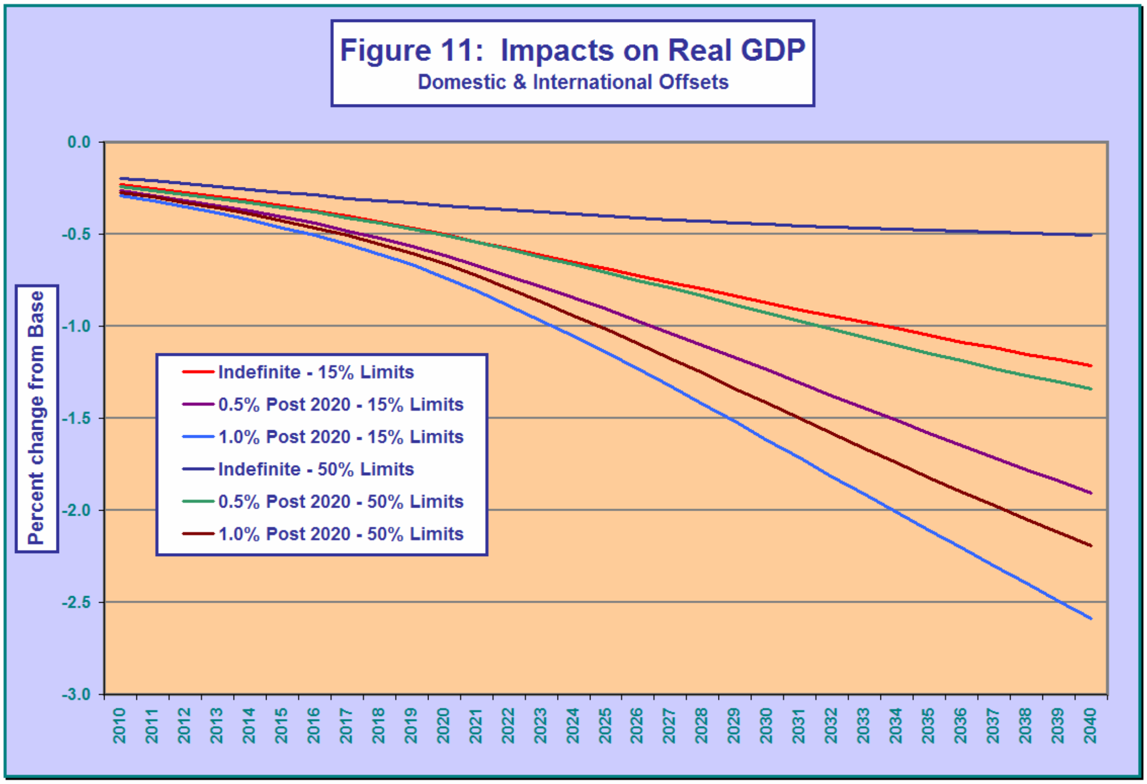


Figure 11: Impacts on Real GDP
Domestic & International Offsets

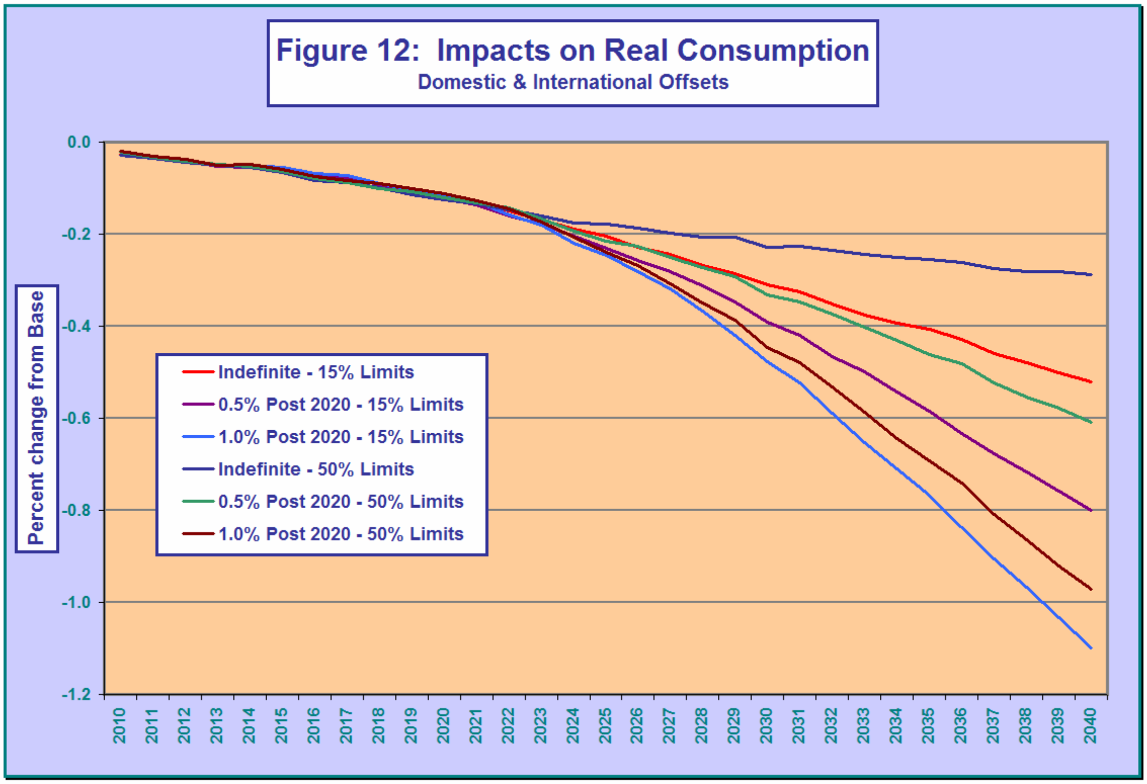


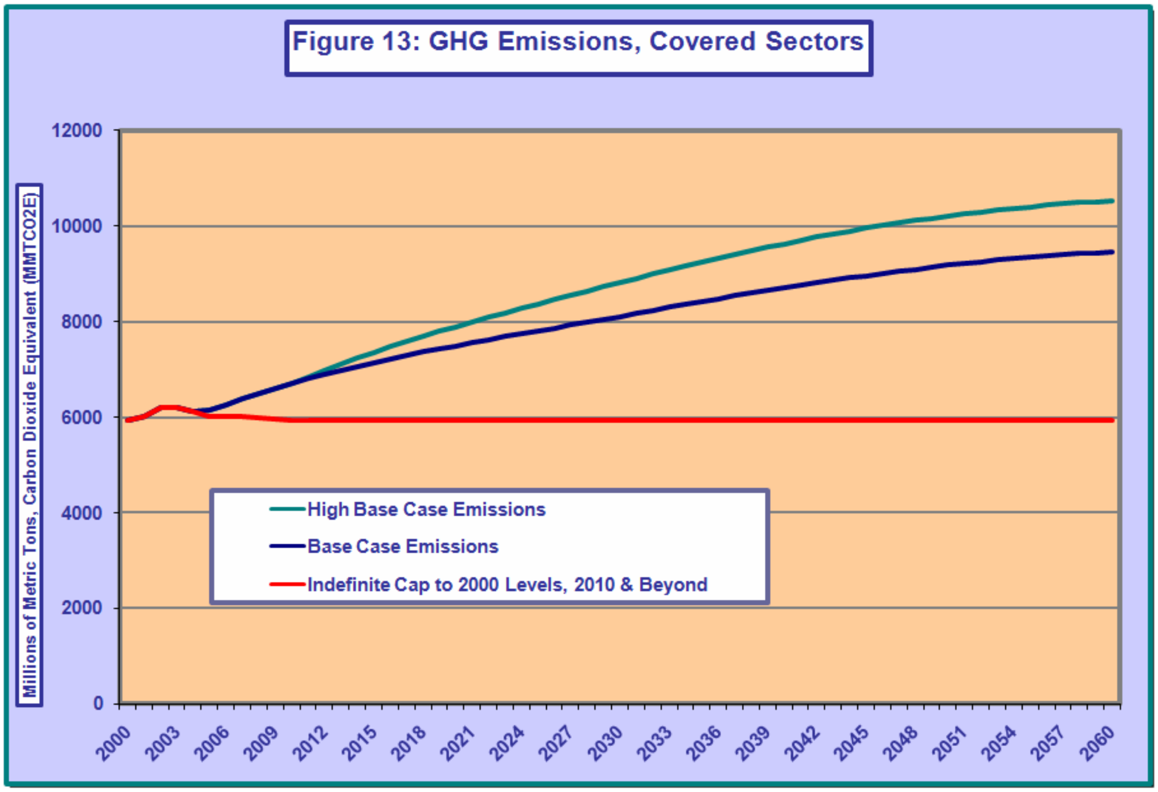
Figure 12: Impacts on Real Consumption
Domestic & International Offsets

The principal findings from these additional simulations are twofold. First, the benefit from more generous offsets diminishes with ever more restrictive constraints. The largest gain from expanding these limits from 15 to 50% occurs when emissions are capped at 2000 levels and held there indefinitely. The second largest gain is when the emissions target, post-2020, is reduced by 0.5% annually. The smallest gain arises under the most severe constraint of a 1.0% annual reduction following 2020. Explaining this diminishing benefit is the fact that the offset allowances follow the emissions cap, becoming less generous as the cap becomes more restrictive. In addition, for any given emissions path, there is a diminishing benefit from the greater use of offsets. This follows directly from the shapes of MAC curves which everywhere in these simulations appear as in Figure 2. Even though more is better than less, allowing the first 15% from these lower cost external sources reduces the overall policy costs by more than allowing the next 35%.

Second, the increases in the policy costs associated with ever more restrictive emissions targets are larger in moving across the 50% cases than they are in moving across the 15% cases. Increasing the severity of the emissions constraint involves greater incremental costs when offsets are more generous and smaller incremental costs when they are less generous. This arises from the scale of the economy and its associated marginal abatement cost schedule. With the more generous offsets, there is more abatement provided by these lower cost offsets. The economy, therefore, is larger and the more restrictive emissions targets prove more costly. With the less generous allowances, the opposite occurs. Thus, the conclusion for policy design on a cost-benefit basis is not to set limits independently from the use of offsets but rather to take their cost and availability into account when first establishing emissions price-quantity targets.

10. Base case sensitivity

More aggressive emissions reductions raise policy costs and signal the importance of underlying base case conditions. If more restrictive constraints prove more harmful then so, too, does an indefinite cap imposed on an economy characterized by higher emissions. Moreover, that higher baseline emissions entail higher policy costs for a given emissions target only strengthens the case for earlier intervention when emissions are, in fact, lower. To examine this, the simulations of Sections 4 and 5 are recast for a new base case involving faster energy and emissions growth over the period 2010-2025. This is shown graphically in Figure 13. Relative to the original base case, GHG emissions from covered sources are 5% higher (7898 MMTCO$_2$E) by 2020, 7% higher (8373 MMTCO$_2$E) by 2025 and 11% higher (9627 MMTCO$_2$E) by 2040. Constraining emissions to 5945 MMTCO$_2$E indefinitely requires abatement in these same years of 1954, 2427 and 3685 MMTCO$_2$E. Under these conditions, required emissions reductions are between 26 and 33% higher over this period.



For comparability, these model runs repeat the provisions of Section 4. Namely, there are two pairs of scenarios involving 15% and 50% limits on external offsets each with and without international permit trading. The alternative compliance options again are evaluated at their economic cost.

Tables 14 and 15 show the sources of abatement and their external costs; these are comparable to Tables 3 and 4 of Section 4. Because required emissions reductions considered in this scenario are larger, there is more abatement occurring from sources within IGEM and a greater use of external offsets. Driven by higher permit prices, the external sources become competitive more quickly, enter the mix earlier and, when constrained, reach their limits faster. When unconstrained, they have a greater presence, though not proportionally so. Obviously, as their use increases, their average cost is higher and their claim on the economy's productive resources increases. But, since they are competitive, the economic costs of this diversion are more than compensated by the release of resources from abatement activities internal to IGEM.

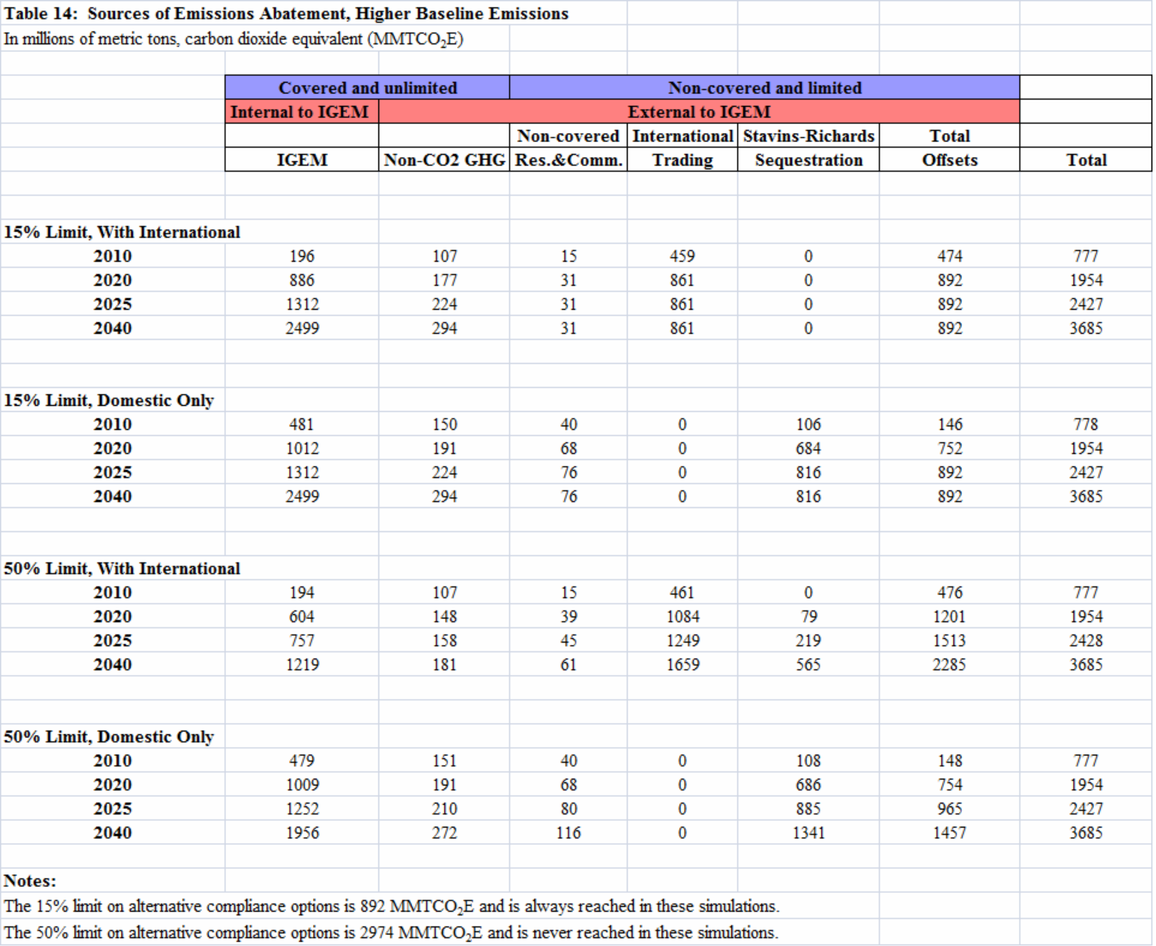


Table 14: Sources of Emissions Abatement, Higher Baseline Emissions

In millions of metric tons, carbon dioxide equivalent (MMTCO_2E)

	Covered and unlimited	Non-covered and limited					
	Internal to IGEM	External to IGEM					
	IGEM	Non-CO2 GHG	Non-covered Res.&Comm.	International Trading	Stavins-Richards Sequestration	Total Offsets	Total
15% Limit, With International							
2010	196	107	15	459	0	474	777
2020	886	177	31	861	0	892	1954
2025	1312	224	31	861	0	892	2427
2040	2499	294	31	861	0	892	3685
15% Limit, Domestic Only							
2010	481	150	40	0	106	146	778
2020	1012	191	68	0	684	752	1954
2025	1312	224	76	0	816	892	2427
2040	2499	294	76	0	816	892	3685
50% Limit, With International							
2010	194	107	15	461	0	476	777
2020	604	148	39	1084	79	1201	1954
2025	757	158	45	1249	219	1513	2428
2040	1219	181	61	1659	565	2285	3685
50% Limit, Domestic Only							
2010	479	151	40	0	108	148	777
2020	1009	191	68	0	686	754	1954
2025	1252	210	80	0	885	965	2427
2040	1956	272	116	0	1341	1457	3685

Notes:

The 15% limit on alternative compliance options is 892 MMTCO_2E and is always reached in these simulations.

The 50% limit on alternative compliance options is 2974 MMTCO_2E and is never reached in these simulations.

Table 15: Abatement Costs External to IGEM, Higher Baseline Emissions

In millions of $(2000)

	Covered and unlimited	Non-covered and limited				
	Non-CO2 GHG	Non-covered Res.&Comm.	International Trading	Stavins-Richards Sequestration	Total Offsets	Total
15% Limit, With International						
2010	-$70	$20	$312	$0	$332	$262
2020	$225	$56	$1,217	$0	$1,273	$1,498
2025	$706	$56	$1,217	$0	$1,273	$1,979
2040	$1,812	$56	$1,217	$0	$1,273	$3,085
15% Limit, Domestic Only						
2010	$56	$97	$0	$519	$616	$672
2020	$344	$299	$0	$4,562	$4,861	$5,205
2025	$702	$371	$0	$5,787	$6,158	$6,859
2040	$1,813	$371	$0	$5,787	$6,158	$7,971
50% Limit, With International						
2010	-$70	$20	$315	$0	$335	$265
2020	$47	$91	$2,193	$385	$2,669	$2,716
2025	$97	$124	$3,054	$1,120	$4,298	$4,395
2040	$251	$236	$5,851	$3,479	$9,566	$9,817
50% Limit, Domestic Only						
2010	$57	$97	$0	$527	$624	$681
2020	$349	$302	$0	$4,613	$4,915	$5,264
2025	$532	$417	$0	$6,537	$6,954	$7,486
2040	$1,356	$1,006	$0	$13,807	$14,814	$16,170

Note:

These costs represent the cumulative abatement costs derived from the external MAC schedules adopted for this analysis.

Table 16 compares the impacts under the two levels of base case emissions. There are ratios, baseline to baseline, of average permit prices as well as the average percentage changes in GDP, consumption, the capital stock, labor supply and leisure demand for two intervals, 2010-2025 and 2025-2040. With few exceptions, the economic costs are greater when baseline emissions are higher. For example, over the period 2025-2040, permit prices average about forty percent higher with 15% limits and about twenty percent higher with 50% limits. This 40%-20% pattern also is observed for the impacts on GDP and the capital stock. Labor supply and leisure demand work in equal and opposite directions. The reductions in labor supply are about 50% greater under the 15% limits and 30 to 40% greater under the 50% limits. The increases in leisure demand are proportionally equivalent in magnitude.

Table 16: The Effects of Higher Baseline Emissions

Percentage Changes in Average Annual Policy Impacts, Higher versus Lower Baselines

	15% Limit on Alternative Compliance Options		**50% Limit on Alternative Compliance Options**	
	With International	**Domestic Only**	**With International**	**Domestic Only**
Increases in GHG Permit Prices				
Due to Higher Baseline Emissions				
2010-2025	47.9%	14.4%	18.2%	13.5%
2025-2040	46.6%	43.1%	23.4%	21.6%
Real GDP				
Original Baseline				
2010-2025	-0.44%	-0.60%	-0.31%	-0.58%
2025-2040	-0.96%	-0.99%	-0.46%	-0.87%
Higher Baseline				
2010-2025	-0.59%	-0.73%	-0.30%	-0.63%
2025-2040	-1.38%	-1.40%	-0.55%	-1.07%
Real Consumption				
Original Baseline				
2010-2025	-0.10%	-0.19%	-0.10%	-0.19%
2025-2040	-0.36%	-0.40%	-0.24%	-0.40%
Higher Baseline				
2010-2025	-0.12%	-0.21%	-0.10%	-0.19%
2025-2040	-0.53%	-0.57%	-0.26%	-0.47%
Capital Stock				
Original Baseline				
2010-2025	-0.47%	-0.67%	-0.34%	-0.65%
2025-2040	-1.10%	-1.15%	-0.56%	-1.03%
Higher Baseline				
2010-2025	-0.62%	-0.80%	-0.32%	-0.69%
2025-2040	-1.58%	-1.61%	-0.64%	-1.24%
Labor Supply (Labor Demand)				
Original Baseline				
2010-2025	-0.36%	-0.46%	-0.23%	-0.45%
2025-2040	-0.67%	-0.67%	-0.26%	-0.55%
Higher Baseline				
2010-2025	-0.51%	-0.58%	-0.25%	-0.52%
2025-2040	-1.00%	-0.98%	-0.36%	-0.73%
Leisure Demand				
Original Baseline				
2010-2025	0.12%	0.15%	0.08%	0.15%
2025-2040	0.22%	0.22%	0.09%	0.18%
Higher Baseline				
2010-2025	0.17%	0.19%	0.08%	0.17%
2025-2040	0.33%	0.32%	0.12%	0.24%

With higher baseline emissions, the losses in consumption are 40 to 50% greater when external offsets are limited to 15% of the cap and 9 to 18% greater under the more generous 50% allowances. In comparisons to the original base case, consumption foregone in 2040 on a per household basis is in the range of $680 with 15% limits, $370 with 50% limits and overseas permit trading, and $630 with 50% offsets from only domestic sources. With higher emissions, these figures are $1050, $460 and $800, respectively.

The patterns observed across scenarios under the lower baseline emissions are repeated here under the higher emissions. With 15% limits, the economic losses are initially larger when only domestic options compete but, ultimately, converge with international participation showing only a slight advantage. With the more generous 50% limits, the economic losses are smaller and, especially so, when foreign permits are available. Under higher baseline emissions, the case with 50% limits and international permit trading incurs the lowest policy costs as it did under the lower baseline.

Most striking is that the gains provided by external offsets increase as baseline emissions increase. The incremental reductions in policy costs secured by raising the limits on these external sources first from 0 to 15% and then from 15 to 50% are greater under the higher baseline emissions than under the lower baseline. This further strengthens the case for allowing these lower cost options to compete in the first place and for allowing still greater use, as economically justified, when policy-enacted emissions reductions become more costly.

11. Summary and Conclusions

The purpose of this exercise is to offer an economic analysis of some of the key policy provisions currently being debated for dealing with climate change. The analysis employs the Inter-temporal General Equilibrium Model (IGEM) of Dale Jorgenson

Associates (DJA) and is structured to highlight those empirical and design issues that most influence policy outcomes.

The overall economic impacts from a modest initiative such as described in this report are estimated to be small. By 2020, the annual losses in real GDP from implementing a similar GHG policy are in the range of 0.5 to 0.7% and reach 1.2% by 2040. The effects on household spending, as measured by foregone consumption, are less than half of these income effects. This translates into losses of $150 to $300 per household by 2020, approaching $700 by 2040. The latter amount is about what households spent in additional energy costs 2006 over 2005 due to the actual increases in energy prices.

While the aggregate costs are small and readily absorbed, there are much larger impacts at the industry level. The energy sectors – coal mining, crude oil and gas extraction, petroleum refining and electric and gas utilities – are hardest hit. By 2020, compliance related reductions in coal use reach 15% with reductions in electricity, oil and gas use in the range from 2 to 3%. As investment and exports are more heavily affected, the capital goods industries experience losses in demand of 3 to 5%. The declines in communications, finance and services are minimal while agricultural and food processing outputs actually increase.

The magnitudes above are heavily influenced by household consumption-saving and labor-leisure decisions. In IGEM, these are determined by two parameters – one governing the tradeoff of consumption for leisure and the other governing the substitutions of full consumption (i.e., consumption *plus* leisure) between periods. The consumption-leisure elasticities are empirically estimated from historical data whereas the inter-temporal substitution elasticity is implicit in the model's specification.

Household decisions on leisure demand simultaneously determine labor supply as these are complements in time. Over various vintages of model estimates, IGEM's top-down view has tended to yield labor supply elasticities toward the upper end of the range observed in the empirical literature. Bottom-up approaches that combine elasticities differing in their demographic detail (for example, by age, sex and-or race) and in the labor force status of their subjects (for example, employee versus entry-exit behaviors) have tended to yield estimates toward the lower end of this range. Which of these are "correct" matters a lot insofar as the magnitudes of policy outcomes. Confining IGEM to these lower elasticity estimates reduces the impacts on GDP and the capital stock by 25 to 33%, on leisure demand and labor supply by almost 50% and on household consumption by 70 to 80%. Unfortunately, there is no consensus on which of these parameter estimates is most representative of what actually will occur. The lack of definitive resolution in this area opens the possibility of smaller policy costs arising from less responsive household behavior.

The empirical content of IGEM permits a first approximation of the effects of induced technical change (ITC) at both the industry and macroeconomic levels. The net effect of ITC economy-wide is to reduce the economic costs of mitigation policy. For GDP and capital formation the cost savings from ITC are in the range of 2 to 6% nearer term and 7 to 10% longer term. Consumers, however, are ITC's main beneficiaries with nearer-term savings in the range of 18 to 22% and longer-term cost reductions in excess of 25%. The benefits from ITC materialize quickly and, as evidenced, increase with time.

The ITC effects in IGEM arise from combining policy-induced changes in relative input prices with empirically observed non-price trends in factor intensities (input cost shares). These trends embody the technological opportunities and choices, unrelated to prices, of the past forty-plus years, 1958-2000. With this perspective, they provide reasonable and plausible initial guesses of the nature and magnitudes of these forces. What is unknown is the degree to which this or any other mitigation policy influences or can be made to influence the trends and biases in innovation. Investment tax credits and other such market incentives, targeted to reducing greenhouse gas emissions and promoting alternative technologies, could accelerate the realization of ITC benefits by further altering the speeds and directions of innovation along with relative prices. Bringing empirical content to the growing literature on policy- and price-induced technical change remains a high priority on the research agenda.

The final concern is related to interest rates and permit banking. Real market interest rates in IGEM are ***simulated***, not assumed. Their role is to equilibrate the balances between saving and investment and between present and future (full) consumption. Behaviorally, they trend toward the economy's long-run marginal physical product of capital and its econometrically estimated social rate of time preference. Near-term rates generally are in the range of 3.0 to 3.5% and systematically decline toward 2.6%. These are far below the rates assumed in other assessments.

Because IGEM's interest rates are comparatively low and annual percentage increases in permit prices are projected to be initially high, the incentive for banking persists well into the future. In comparing outcomes with and without banking, economic costs are comparatively larger over the interval in which permits are accumulated and comparatively smaller as banked permits are withdrawn and used. With lower interest rates, the net, present-value gains from banking take a long time to materialize and favorable policy evaluations will require a longer time horizon to achieve because near-term costs are even more dominant.

Real-world uncertainties aside, the time profile of banking ultimately depends on the evolving patterns of permit prices relative to interest rates. Thus, banking and its consequences are "live" outcomes of the responses to policy enactment. If net gains are realized quickly then banking improves present-value benefit-cost comparisons. However, if net gains take much longer to materialize then banking worsens these comparisons. There is no way to know ahead of time which of these would prevail.

The principal conclusion of this analysis concerns the limits independently placed on emissions offsets from households, small businesses, domestic sequestration and international permit purchases. These alternatives offer abatement at a lower cost than can be secured elsewhere within the activities covered by policy. As such, their presence reduces the already small economic costs of mitigation policy. Moreover, the benefits from allowing the use of these offsets increase as the required abatement increases.

While there are shown to be diminishing benefits from ever more generous offsets usage, there are, nevertheless, benefits to be obtained to the point where these sources are no longer competitive. In the spirit of market-based incentives, the limits governing the use of marketable and verifiable abatement offsets should arise solely from their "economics" within an overall, present-value assessment of policy benefits and costs.

Finally, there is the matter of the ultimate context for this analysis. The goal of any climate policy will be to balance the benefits and costs of climate change and climate change policy. Arguably, there are already private costs associated with government and business mitigation initiatives just as there are already damages associated with climate change (Smith J.B., 2004). Some of these damages are market-based and are numerically comparable to the economic costs of climate change policy (Jorgenson, Goettle, et al., 2004). Policy-driven reductions in emissions will lead to lower greenhouse gas concentrations. In turn, these will have favorable impacts on climate in terms of their effects on temperatures, precipitation, storms, floods and the like. The favorable outcomes for climate produce both market and non-market benefits in the form of delayed or avoided damages. At a minimum, the market benefits help to reduce the net economic costs of environmental policy. At their best, the market benefits more than compensate policy costs and, thus, economically justify timely enactment.

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Appendix A
Emissions Projections and Abatement Opportunities in the Inter-temporal General Equilibrium Model (IGEM)

A1. Introduction

The Inter-temporal General Equilibrium Model (IGEM) is equipped with a number of array-based "externality" variables that are conceptually and empirically defined to suit the needs of a particular analysis. Currently, there are four such variables aiding in the assessment of the benefits and costs of climate change and climate change mitigation policies. These are:

1. Carbon emissions arising from fossil fuel use in millions of metric tons carbon dioxide equivalent (MMTCO$_2$E);
2. Fossil fuel use in physical units, quadrillion Btu;
3. An approximation of the greenhouse gas (GHG) emissions in MMTCO$_2$E arising from the economic activities covered by the policy scenario. Notably, the scenario exempts GHG emissions originating in agriculture and by households and small businesses whereas the IGEM construct is total GHG emissions less those from agriculture and residential and commercial energy use;
4. A composite of total GHG in MMTCO$_2$E covering all gases arising from all sources.

"Externalities" in IGEM are considered as joint outputs or products of the economic activities represented within its structure. These may be process related in that they arise from the creation and manufacture of a particular good or service or they may be product related in that they arise from the economy's use of a particular good or service. In either case, the annual level of each composite externality is jointly determined by the production and consumption activities that give rise to it and, in turn, these activities are associated with the processes and products of domestic industries and with corresponding U.S. imports.

A2. Emissions Projections

The development of IGEM's externality coefficients for energy and the environment is derived from detailed historical data appearing in EPA's *2004 Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2002* and EIA's *Monthly Energy Review*. These series are sorted and aggregated (see Table A1) to create the energy and emissions totals corresponding to the four externality variables defined above. The totals then are expressed relative to the underlying sector-specific economic outputs that give rise to them. It is worth noting that none of the externality coefficients is trendless over the period 1990-2000 which further highlights the difficulties in projecting them (see Figure A1).

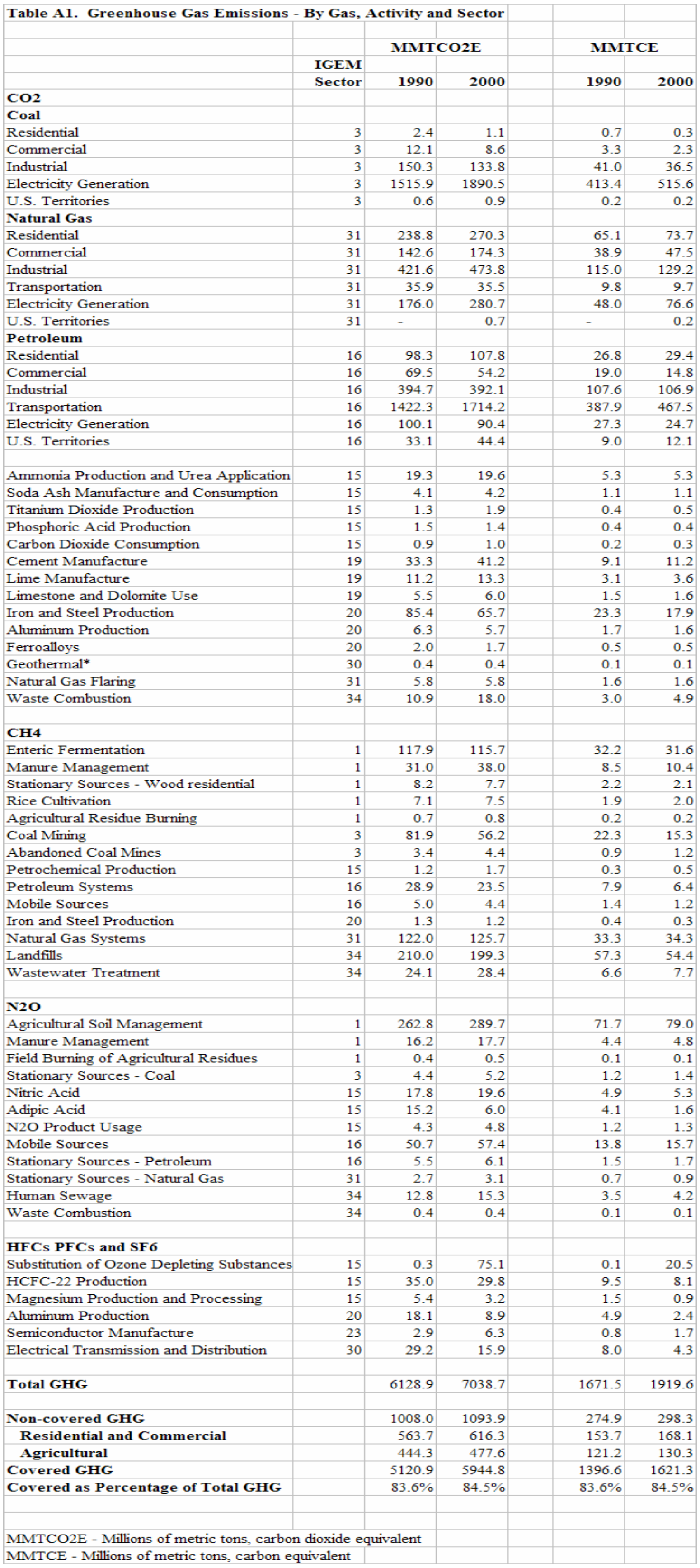
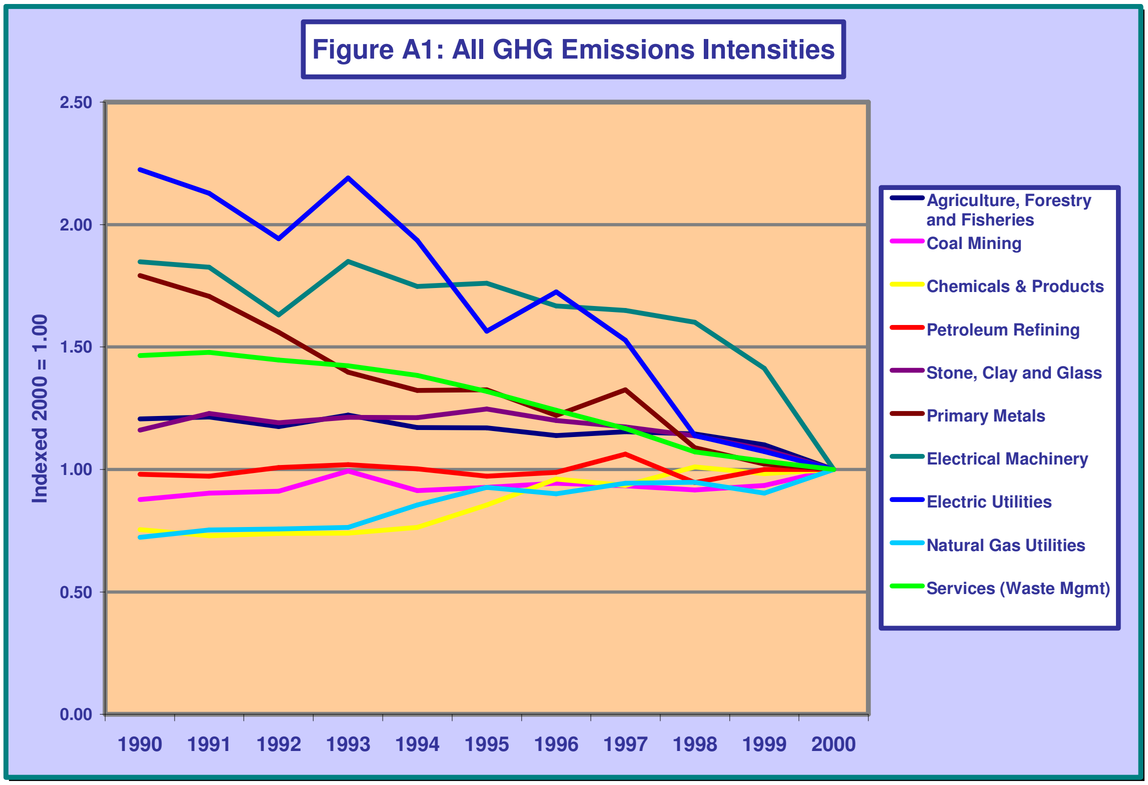


Table A1. Greenhouse Gas Emissions - By Gas, Activity and Sector

		MMTCO2E		MMTCE	
	IGEM Sector	1990	2000	1990	2000
CO2					
Coal					
Residential	3	2.4	1.1	0.7	0.3
Commercial	3	12.1	8.6	3.3	2.3
Industrial	3	150.3	133.8	41.0	36.5
Electricity Generation	3	1515.9	1890.5	413.4	515.6
U.S. Territories	3	0.6	0.9	0.2	0.2
Natural Gas					
Residential	31	238.8	270.3	65.1	73.7
Commercial	31	142.6	174.3	38.9	47.5
Industrial	31	421.6	473.8	115.0	129.2
Transportation	31	35.9	35.5	9.8	9.7
Electricity Generation	31	176.0	280.7	48.0	76.6
U.S. Territories	31	-	0.7	-	0.2
Petroleum					
Residential	16	98.3	107.8	26.8	29.4
Commercial	16	69.5	54.2	19.0	14.8
Industrial	16	394.7	392.1	107.6	106.9
Transportation	16	1422.3	1714.2	387.9	467.5
Electricity Generation	16	100.1	90.4	27.3	24.7
U.S. Territories	16	33.1	44.4	9.0	12.1
Ammonia Production and Urea Application	15	19.3	19.6	5.3	5.3
Soda Ash Manufacture and Consumption	15	4.1	4.2	1.1	1.1
Titanium Dioxide Production	15	1.3	1.9	0.4	0.5
Phosphoric Acid Production	15	1.5	1.4	0.4	0.4
Carbon Dioxide Consumption	15	0.9	1.0	0.2	0.3
Cement Manufacture	19	33.3	41.2	9.1	11.2
Lime Manufacture	19	11.2	13.3	3.1	3.6
Limestone and Dolomite Use	19	5.5	6.0	1.5	1.6
Iron and Steel Production	20	85.4	65.7	23.3	17.9
Aluminum Production	20	6.3	5.7	1.7	1.6
Ferroalloys	20	2.0	1.7	0.5	0.5
Geothermal*	30	0.4	0.4	0.1	0.1
Natural Gas Flaring	31	5.8	5.8	1.6	1.6
Waste Combustion	34	10.9	18.0	3.0	4.9
CH4					
Enteric Fermentation	1	117.9	115.7	32.2	31.6
Manure Management	1	31.0	38.0	8.5	10.4
Stationary Sources - Wood residential	1	8.2	7.7	2.2	2.1
Rice Cultivation	1	7.1	7.5	1.9	2.0
Agricultural Residue Burning	1	0.7	0.8	0.2	0.2
Coal Mining	3	81.9	56.2	22.3	15.3
Abandoned Coal Mines	3	3.4	4.4	0.9	1.2
Petrochemical Production	15	1.2	1.7	0.3	0.5
Petroleum Systems	16	28.9	23.5	7.9	6.4
Mobile Sources	16	5.0	4.4	1.4	1.2
Iron and Steel Production	20	1.3	1.2	0.4	0.3
Natural Gas Systems	31	122.0	125.7	33.3	34.3
Landfills	34	210.0	199.3	57.3	54.4
Wastewater Treatment	34	24.1	28.4	6.6	7.7
N2O					
Agricultural Soil Management	1	262.8	289.7	71.7	79.0
Manure Management	1	16.2	17.7	4.4	4.8
Field Burning of Agricultural Residues	1	0.4	0.5	0.1	0.1
Stationary Sources - Coal	3	4.4	5.2	1.2	1.4
Nitric Acid	15	17.8	19.6	4.9	5.3
Adipic Acid	15	15.2	6.0	4.1	1.6
N2O Product Usage	15	4.3	4.8	1.2	1.3
Mobile Sources	16	50.7	57.4	13.8	15.7
Stationary Sources - Petroleum	16	5.5	6.1	1.5	1.7
Stationary Sources - Natural Gas	31	2.7	3.1	0.7	0.9
Human Sewage	34	12.8	15.3	3.5	4.2
Waste Combustion	34	0.4	0.4	0.1	0.1
HFCs PFCs and SF6					
Substitution of Ozone Depleting Substances	15	0.3	75.1	0.1	20.5
HCFC-22 Production	15	35.0	29.8	9.5	8.1
Magnesium Production and Processing	15	5.4	3.2	1.5	0.9
Aluminum Production	20	18.1	8.9	4.9	2.4
Semiconductor Manufacture	23	2.9	6.3	0.8	1.7
Electrical Transmission and Distribution	30	29.2	15.9	8.0	4.3
Total GHG		6128.9	7038.7	1671.5	1919.6
Non-covered GHG		1008.0	1093.9	274.9	298.3
Residential and Commercial		563.7	616.3	153.7	168.1
Agricultural		444.3	477.6	121.2	130.3
Covered GHG		5120.9	5944.8	1396.6	1621.3
Covered as Percentage of Total GHG		83.6%	84.5%	83.6%	84.5%

MMTCO2E - Millions of metric tons, carbon dioxide equivalent

MMTCE - Millions of metric tons, carbon equivalent



In developing baseline projections, there are four inter-related issues. These are:

1. What weight should be attached to each emission factor when dealing with such aggregated sectors?
2. How should emissions coefficients change over time to reflect compositional changes within a sector?
3. To what extent should historical or anticipated mitigation be stripped from or preserved in coefficient trends?
4. To what degree are externality outcomes to be calibrated either to historical data or to "official" projections?

Ideally, and data permitting, analyses should be conducted for each gas and each economic activity; that is, trend first and then aggregate. This solves the problems of weighting and compositional changes and gets the baseline "right." Invariably, however, time and data are unaffordable luxuries. More often than not, aggregation occurs prior to trending. The biases that this introduces in baseline emissions paths can be overcome, however, through development and use of alternative base cases that are directionally appropriate to these biases.

Decisions on trends in mitigation are conditional on the objectives and circumstances of the particular analysis to which the model is being applied. Changes in emissions intensities are both market and policy driven. The extent to which policy driven mitigation is to be left in or stripped from the emissions coefficients depends on whether the particular policy is part of the current assessment. If it is independent then the effects of mitigation should remain; however, if the analysis is retrospective in nature and a portion of the observed mitigation is policy dependent then it should be parsed from the emissions coefficients. The process of isolating the market and policy causes of changes in emissions intensities is obviously much easier the more disaggregated are the data used in their construction.

Calibration is also a matter that depends on the particular analysis; it is generally more important in comparative assessments than it is in those in which a model analysis stands alone. Matching or tracking emissions levels, be they historical or projected, requires either calibrating the variables that drive emissions (and) or adjusting the joint production of emissions per unit of economic activity.

In the current base case, the details of energy use (coal, oil, gas and electricity) in IGEM are consistent with historical data and, generally, with the projections from EIA's 2005 Annual Energy Outlook (AEO). Emissions are calibrated to match the 2000 levels represented in EPA's 2004 emissions inventory. The emissions coefficients for fossil fuels (coal, oil and gas) are held temporally fixed while a common trend, dampening to achieve steady state, is adopted for those coefficients attached to all other economic activities (e.g., agriculture, chemicals, metal manufacturing, electricity transmission and distribution, etc.). For the future, in developing baseline emissions paths, each of the underlying relationships between emissions outcomes and their driving forces merits more analysis and evaluative scrutiny. With its diversity of detail, IGEM then could reflect more fully the payoffs from bottom-up investigations of emissions sources.

A3. Endogenizing Exogenous Abatement Opportunities

Were the emissions intensities of output unresponsive to market or policy driven changes and were all market and technological possibilities fully represented within a model's structure, there would be no need for additional work. Marginal abatement cost schedules derived from model simulations would accurately characterize the economic costs associated with all of the substitutions and all of the market and technological changes that follow from the implementation of a particular mitigation strategy. But emissions intensities are not unresponsive to market circumstances or policy initiatives, and a given model may not fully represent all of the market and technical opportunities that may serve future mitigation. To the extent that abatement possibilities, above and beyond those implicit in a given model, ***and*** their associated costs can be identified, there naturally emerges the question of integration. IGEM employs the following process in endogenizing these external abatement opportunities.

1. For each GHG and each economic activity, those mitigation possibilities are identified that are likely to be adequately represented in IGEM's response to a given policy initiative. These are considered to be internal to IGEM as are the economic costs associated with their implementation. All other possibilities are external to IGEM and require external abatement cost schedules. Currently, all foreseeable abatement opportunities related to carbon emissions are viewed as internal; that is, marginal abatement cost schedules derived from IGEM simulations accurately portray all the economic costs of their intermediate-term mitigation. External to IGEM are those abatement opportunities related to residential and commercial mitigation strategies, non-CO_2 greenhouse gases, international greenhouse gas permit trading, and domestic sequestration (see Table A2 and Figure A2).

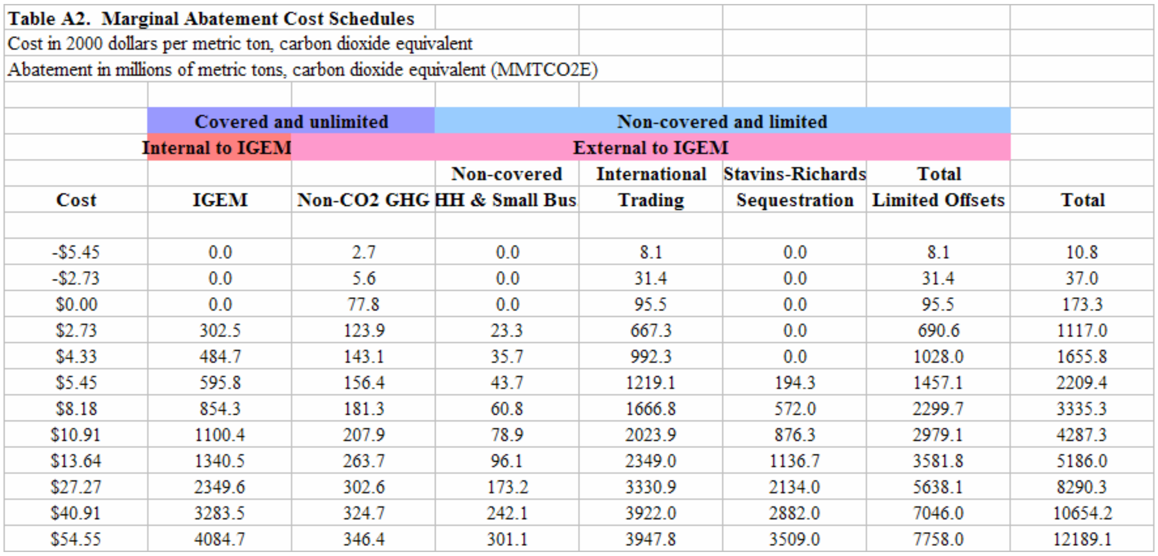


Table A2. Marginal Abatement Cost Schedules

Cost in 2000 dollars per metric ton, carbon dioxide equivalent

Abatement in millions of metric tons, carbon dioxide equivalent (MMTCO2E)

	Covered and unlimited		Non-covered and limited				
	Internal to IGEM	External to IGEM					
			Non-covered	International	Stavins-Richards	Total	
Cost	**IGEM**	**Non-CO2 GHG**	**HH & Small Bus**	**Trading**	**Sequestration**	**Limited Offsets**	**Total**
-$5.45	0.0	2.7	0.0	8.1	0.0	8.1	10.8
-$2.73	0.0	5.6	0.0	31.4	0.0	31.4	37.0
$0.00	0.0	77.8	0.0	95.5	0.0	95.5	173.3
$2.73	302.5	123.9	23.3	667.3	0.0	690.6	1117.0
$4.33	484.7	143.1	35.7	992.3	0.0	1028.0	1655.8
$5.45	595.8	156.4	43.7	1219.1	194.3	1457.1	2209.4
$8.18	854.3	181.3	60.8	1666.8	572.0	2299.7	3335.3
$10.91	1100.4	207.9	78.9	2023.9	876.3	2979.1	4287.3
$13.64	1340.5	263.7	96.1	2349.0	1136.7	3581.8	5186.0
$27.27	2349.6	302.6	173.2	3330.9	2134.0	5638.1	8290.3
$40.91	3283.5	324.7	242.1	3922.0	2882.0	7046.0	10654.2
$54.55	4084.7	346.4	301.1	3947.8	3509.0	7758.0	12189.1

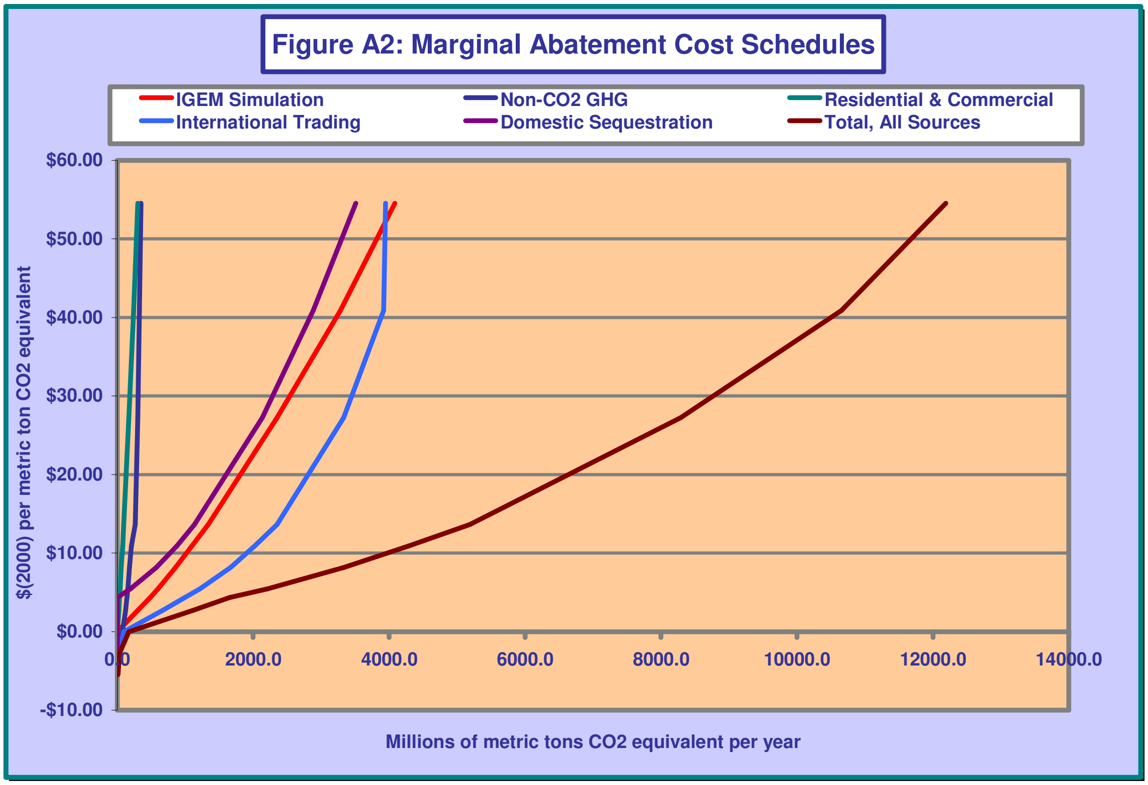


Figure A2: Marginal Abatement Cost Schedules

2. IGEM is simulated to ascertain its response to the particular mitigation policy. This generates an initial marginal abatement cost (MAC) schedule that serves as the starting point of an iterative process. Typically, this step involves imposing

an emissions constraint and observing its corresponding path of permit prices or introducing a path of permit prices and observing its corresponding abatement.

3. The marginal abatement cost schedule from step two (or step six below) is summed horizontally with those cost schedules external to IGEM to create an aggregate marginal abatement cost schedule.
4. The targeted or required level of abatement then is "read" from this schedule and the allocation of abatement to each of the external and internal categories is determined. Because some abatement is being provided from sources external to IGEM, the constraint in IGEM is relaxed or, equivalently, permit prices are reduced.5. Having determined the abatement benefits from external sources, it is also necessary to calculate and introduce their economic costs. These are determined by integrating the areas underneath the external MAC schedules in accordance with their allocated amounts of abatement and introducing these costs directly into IGEM. International permit trading is treated as a factor payment (e.g., rent on a tangible asset or income on a financial asset) and is presumed to substitute for a portion of the current account deficit that arises from trade. The costs associated with domestic sequestration are assumed to be borne entirely by IGEM's agriculture, forestry and fisheries sector. All other costs are allocated to emissions generating activities in proportion to their contributions to baseline GHG emissions. In addition, all costs save those associated with international permit trading are introduced as factor-neutral, or unbiased, changes in input-to-output relationships.
6. IGEM then is re-simulated with less "internal" abatement (or lower permit prices) arising from more "external" abatement purchased with the now endogenized, additional input requirements implicit in the external abatement cost schedules. This yields a new schedule of IGEM marginal abatement costs.
7. Steps three through six are repeated until IGEM's (internal) marginal abatement cost schedule no longer changes from one iteration to another; experience has shown this to be anywhere from one to six iterations of the aforementioned.

The procedure outlined above, though different mechanically, is identical in spirit and outcome to that implemented in the Emissions Prediction and Policy Analysis (EPPA) Model of MIT's Joint Program on the Science and Policy of Climate Change (see Hyman, et al., 2002). The iterative process adopted here sacrifices the computational efficiency of the MIT approach to gain fuller use of the informational content portrayed in the external MAC schedules, most specifically, the areas of "no regrets," their precise curvatures and the points at which they become inelastic. Beyond these differences, both approaches succeed in offering quite reasonable ways to endogenize those market and technological abatement opportunities (and their costs) that are identified as lying outside the boundaries of the possibilities inherent in a model's responses.

Appendix B
The Inter-temporal General Equilibrium Model (IGEM) and Projections

B1.1. Overview of the Model

The Inter-temporal General Equilibrium Model (IGEM) is a dynamic model of the U.S. economy which describes growth due to capital accumulation, technical change and population change. It is a multi-sector model that tracks changes in the composition of industry output, as well as changes in input mix used by each industry, including energy use. It also depicts changes in consumption patterns due to demographic changes, price and income effects.

The main driver of economic growth in this model is capital accumulation and technological change. Capital accumulation arises from savings of a household that is modeled as an economic actor with "perfect foresight." Aggregate household consumption and savings are chosen to maximize a utility function that is a discounted sum of the stream of future consumption. Within each period, the consumption – or demand – side of the model is driven by a detailed model of household demand that includes demographic characteristics.

The production – or supply – side of the model characterizes the industrial structure in detail. 35 industries are identified, of which 21 are manufacturing and 5 are energy related, these are listed in Table B1. Each industry produces output using capital, labor, energy and non-energy intermediate inputs using constant returns to scale technology. The production technology used changes over time due to both exogenously specified changes and endogenous changes from price effects. Coal, refined oil and gas are separately identified energy inputs. The output from domestic industries is supplemented by imports from the rest of the world to form the total supply of each commodity.

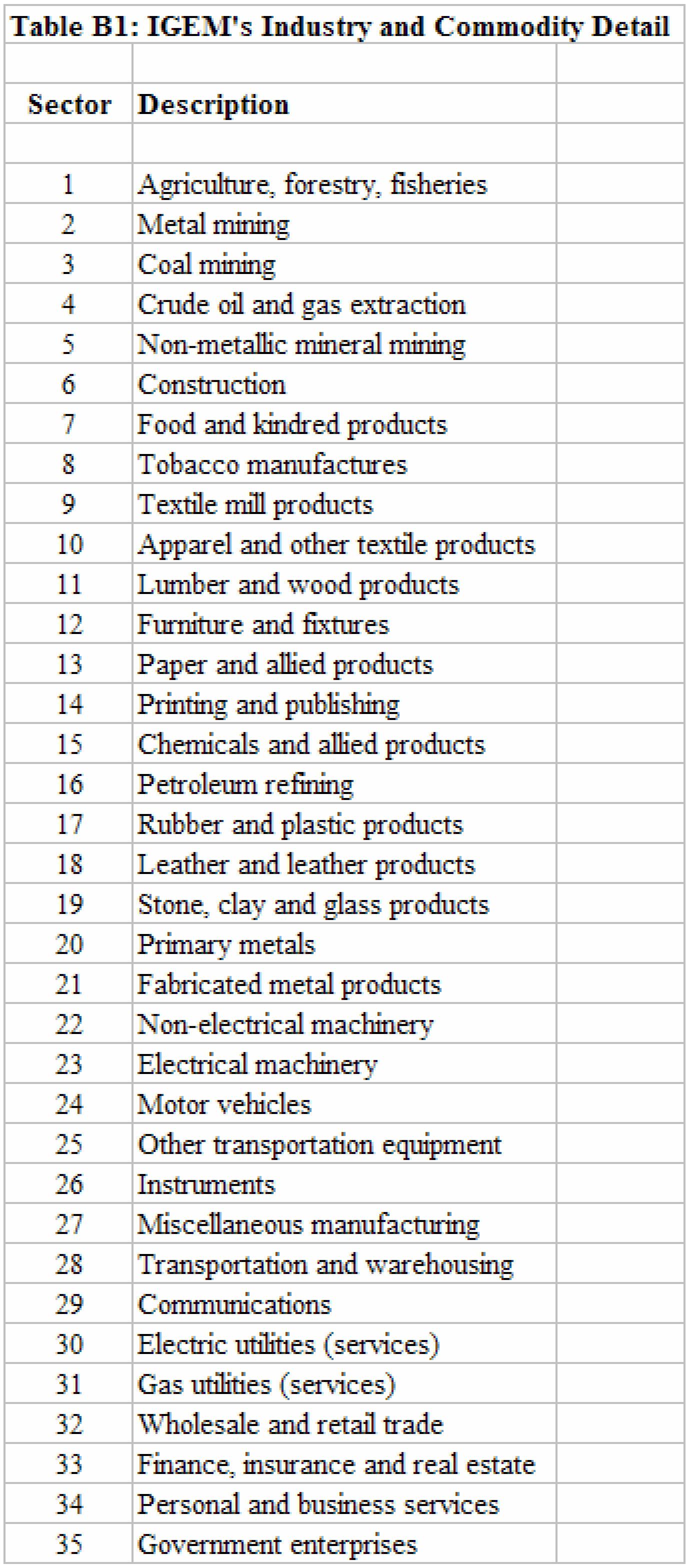


Table B1: IGEM's Industry and Commodity Detail

Sector	Description	
1	Agriculture, forestry, fisheries	
2	Metal mining	
3	Coal mining	
4	Crude oil and gas extraction	
5	Non-metallic mineral mining	
6	Construction	
7	Food and kindred products	
8	Tobacco manufactures	
9	Textile mill products	
10	Apparel and other textile products	
11	Lumber and wood products	
12	Furniture and fixtures	
13	Paper and allied products	
14	Printing and publishing	
15	Chemicals and allied products	
16	Petroleum refining	
17	Rubber and plastic products	
18	Leather and leather products	
19	Stone, clay and glass products	
20	Primary metals	
21	Fabricated metal products	
22	Non-electrical machinery	
23	Electrical machinery	
24	Motor vehicles	
25	Other transportation equipment	
26	Instruments	
27	Miscellaneous manufacturing	
28	Transportation and warehousing	
29	Communications	
30	Electric utilities (services)	
31	Gas utilities (services)	
32	Wholesale and retail trade	
33	Finance, insurance and real estate	
34	Personal and business services	
35	Government enterprises	

There are four main sectors of the economy in IGEM: business, household, government and the rest of the world. The flow of goods and factors among these sectors is illustrated in Figure B1. The boxes on the right side of the diagram represent the five groups on the demand side for commodities -- consumption, investment, government, exports and intermediate purchases. The business sector is represented by the boxes on the left; labor, capital and intermediate inputs flow into the producer box, and domestic commodities flow out. All markets for goods and factors are assumed to be competitive. Prices of commodities adjust to equate the supply from domestic and foreign producers to the demand in each period, as represented at the bottom of Figure B1.

This model is implemented econometrically, by which is meant that the parameters governing the behavior of producers and consumers are statistically estimated over a time series dataset that is constructed specifically for this purpose. This is in contrast to many other multi-sector models that are calibrated to the economy of one particular year. These data are based on a system of national accounts developed by Jorgenson (1980) that integrates the capital accounts with the National Income Accounts. These capital accounts include an equation linking the price of investment goods to the stream of future rental flows, a link that is essential to modeling the dynamics of growth.

This model is an extension and revision of the one used in Jorgenson and Wilcoxen (1993), and Ho and Jorgenson (1994) to analyze environment and trade policies[11]. The following sections describe the main features of the model.

B1.2. The production and supply of commodities.

Energy consumption per person, like most goods, depends on the price of energy and the level of income. These, in turn, ultimately depend on technology, and to some extent, on world supplies. General progress in technology means a rising level of real incomes, progress in particular energy technologies means lower energy prices or lower energy requirements. A careful specification of producer behavior and technical change is thus essential for analyses of future energy trends and responses to energy and environmental policies. The response of firms to changes in prices determines to an important degree the ability of the producers to substitute other inputs for energy. In the long run, productivity growth allows both higher personal consumption and pollution

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[11] Jorgenson and Wilcoxen (1993) is reprinted as Chapter 1 of Jorgenson (1998), and Ho and Jorgenson (1994) is Chapter 8.

reduction. The exact specification and parameterization of the production and technical change are therefore very important and described in detail in this section.

The business sector of the model is subdivided into 35 industries as listed in Table B1. There are two additional sectors that are not private businesses, but also hire labor and capital; these are the government and household sectors. There are 21 manufacturing industries, 4 mining industries, and 1 transportation industry. Five of the industries are labeled as energy producers, Coal Mining (industry 3), Oil and Gas Extraction (4), Petroleum Refining (16), Electric Utilities (30) and Gas Utilities (31). Seven are classified as intensive energy using industries, these are industries with value share of energy inputs in total output exceeding 4% in 1995.

The output of the business sector also is subdivided into 35 commodities; each commodity is the primary product of one of the industries. Many industries produce secondary products as well, for example, Petroleum Refining produces commodities that are the primary output of the Chemicals industry. Joint production of this kind is allowed for in the model.

The technology of each industry is represented by means of an econometric model of producer behavior. As noted in the Introduction the parameters of these production functions are estimated over a database constructed for this purpose, based on a system of national accounts developed by Jorgenson (1980). This database includes a time series of inter-industry transactions tables covering the period 1958-2000.

These input-output (IO) tables consist of a *use* matrix and a *make* matrix. The use matrix gives the inputs used by each industry -- intermediate commodities, non-competing imports, capital and labor. It also gives the commodity use by each category of final demand -- consumption, investment, government, exports and imports. The use matrix is illustrated in Figure B2. The make matrix gives the amount of each commodity produced by each industry and is illustrated in Figure B3.

The IO tables include the value of capital and labor input. The system of accounts includes a division of this value into price and quantity. The quantity of capital input is constructed by aggregating over a detailed set of capital assets, ranging from computers to office buildings. Similarly the quantity of labor input is constructed by aggregating over demographic groups, ranging from young workers with high school education to old workers with masters degrees. (A detailed description of the methods to calculate capital and labor input, and the data sources, is given in the Jorgenson, Ho and Stiroh (2003)).

The approach of calculating inputs by aggregating over detailed categories and econometrically estimating production function parameters over a time series dataset stands in contrast to most other multi-sector models, static or dynamic. A simple sum of capital stocks will have ignored the rapidly rising ratio of computers to structures, a phenomenon that is captured by IGEM's index of capital input. Similarly, a simple sum of labor hours ignores the rising ratio of college educated to non-college workers, which raises IGEM's quantity index of labor input substantially. The common method of calibrating the use of intermediate inputs to one year's IO matrix, instead of using an entire time series, ignores the changing pattern of input use. A parallel assumption that is typically made is that input-output material coefficients are fixed, i.e., there is no substitution between steel and plastic, for example.[12] IGEM's approach does not impose such assumptions as it embodies estimates of the elasticities of substitution among productive inputs using time series data.

B1.2.1. Notation

The general system of notation within IGEM employs Roman letters for economic variables and Greek letters for estimated model parameters. The *t* subscript denotes time, *i* indexes commodities and *j* indexes industries.

Q_j	quantity of output of industry *j*
$P_{Q,j}$	price of output to producer in industry *j*
$P_{QT,j}$	price of output to purchasers from industry *j*
$X_{i,j}$	quantity of commodity input *i* into industry *j*
P_i^X	price of commodity *i* to buyers
K_j	quantity of capital input into j
L_j	quantity of labor input into j
E_j	index of energy intermediate input into j
M_j	index of total nonenergy intermediate input into j
$P_{E,j}$	price of energy intermediate input into j

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[12] Some models specify a Cobb-Douglas form for material inputs instead of this "Leontief" style fixed coefficients. This means that the elasticity of substitution is assumed to be one. In contrast, the approach in IGEM estimates the elasticities of substitution, allowing them to be different among inputs and industries.

$P_{M,j}$	price of total nonenergy intermediate input into *j*
$P_{K,j}$	price of total capital input to industry *j*
$P_{L,j}$	price of total labor input to industry *j*
v	value shares
QC_i	quantity of domestically produced commodity *i*
$P_{C,i}$	price of domestically produced commodity *i*
$M_{j,i}$	MAKE matrix; value of commodity *i* made by industry *j*

B1.2.2. Top tier production function with technical change

The production function may be expressed abstractly as producing output from capital, labor, *m* intermediate inputs, non-competing imports (X_N) and technology (t), and thus for industry *j*:

$$Q_j = f(K_j, L_j, X_{1,j}, X_{2,j}, \ldots X_{m,j}, X_{Nj}, t), \qquad j=1,2,\ldots 35 \tag{1}$$

This is too general to be tractable and, so, it is assumed that inputs are chosen based on a multi-stage allocation. At the first stage, the value of each industry output is allocated to four input groups -- capital, labor, energy and non-energy materials:

$$\begin{aligned} Q_j &= f(K_j, L_j, E_j, M_j, t); \\ E_j &= E(X_{3j}, X_{4j} X_{16j} X_{30j} X_{31j}) \\ M_j &= M(X_{1j}, \ldots X_{35j}, X_{Nj}) \end{aligned} \tag{2}$$

The second stage allocates the energy and non-energy materials groups to the individual intermediate commodities. The components of the energy group are Coal, Oil and Gas Extraction, Petroleum Refining, Electric Utilities, and Gas Utilities. The materials group includes all the other 30 commodities listed in Table B1 as well as non-competing imports (X_{Nj}). This last item are imports that are regarded as having no close domestic substitutes and include goods such as coffee and foreign port services.

Production is assumed to occur under constant returns to scale and the value of industry output is equal to the sum of the values of all inputs:

$$\begin{aligned} P_{Qjt} Q_{jt} &= P_{Kjt} K_{jt} + P_{Ljt} L_{jt} + P_{Ejt} E_{jt} + P_{Mjt} M_{jt} \\ P_{Ejt} E_{jt} &= p^X_{3t} X_{3jt} + p^X_{7t} X_{7jt} + .. + p^X_{11t} X_{11jt} \\ P_{Mjt} M_{jt} &= p^X_{1t} X_{1jt} + p^X_{2t} X_{2jt} + .. + p^X_{Nt} X_{Njt} \end{aligned} \tag{3}$$

It is more convenient to work with the dual cost function instead of the direct quantity function in equation (2)[13]. The cost function expresses the unit output price as a function of all the input prices and technology, $P_{Qj} = p(P_{Kj}, P_{Lj}, P_{Ej}, P_{Mj}, t)$. The form of the cost function is chosen as the translog form:

$$(4) \qquad \ln P_{Qt} = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln P_{it} + \tfrac{1}{2} \sum_{i,k} \beta_{ik} \ln P_{it} \ln P_{kt} + \sum_{i=1}^{n} \ln P_{it} f_{it} + f_{pt}$$

$$i,k=\{K,L,E,M\}$$

where the industry j subscript is dropped for simplicity, and α_0, α_i and β_{ik} are parameters that are estimated separately for each industry. The f_{it}'s are state variables representing biases in technical change and f_{pt} is the state variable for the level of neutral technology. f_{pt} is referred to as the price technology term. These f's are unknown functions of time and are estimated using the Kalman filter (see Jorgenson et al. (2004) and Jorgenson and Hui Jin (2005 and 2006)).

The above formulation has a more flexible form for technology than that in the previous version of IGEM. In Jorgenson (1998) the cost function was written in a parametric form:

$$(5) \quad \ln P_{Qt} = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln p_{it} + \tfrac{1}{2} \sum_{i,k} \beta_{ik} \ln p_{it} \ln p_{kt} + \sum_{i=1}^{n} \beta_{it} \ln p_{it} g(t) + \alpha_t g(t) + \tfrac{1}{2} \beta_{tt} g(t)^2$$

where the g(t) function was an index of the level of technology and was assumed to have a logistic form. This new version of IGEM does not impose an explicit parametric form on g(t).

The substitution terms are the same in equations (4) and (5) and are described in detail in Jorgenson (1986). The reason for choosing the translog form is that it is rich enough to allow for substitution among all inputs and for biases in technical change while yielding a simple linear input demand equation. Differentiating equation (4) with respect to the log of input prices yields input share equations. For example, the demand for capital is derived from the capital share equation:

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[13] The dual function is equivalent to the primal function; all the information expressed in one is recoverable from the other.

(6) $$v_{Kt} = \frac{P_K K}{P_Q Q} = \alpha_K + \sum_k \beta_{Kk} \ln P_{kt} + f_{Kt}$$

In more compact vector notation the cost function and share equation may be written as:

(4’) $$\ln P_{Qt} = \alpha_0 + \boldsymbol{\alpha}' \ln \mathbf{p}_t + \tfrac{1}{2} \ln \mathbf{p}_t ' \mathbf{B} \ln \mathbf{p}_t + \ln \mathbf{p}_t ' \mathbf{f}_t + f_{pt} + \varepsilon_t^p$$

(6’) $$\mathbf{v}_t = \boldsymbol{\alpha} + \mathbf{B} \ln \mathbf{p}_t + \mathbf{f}_t + \boldsymbol{\varepsilon}_t^v$$

where $\mathbf{p} = (P_K, P_L, P_E, P_M)'$, $\mathbf{v} = (v_K, v_L, v_E, v_M)'$, $\mathbf{f}_t = (f_{Kt}, f_{Lt}, f_{Et}, f_{Mt})'$ and $\mathbf{B} = [\beta_{ik}]$. The ε_t^p and $\boldsymbol{\varepsilon}_t^v$ terms are stochastic variables with mean zero that are added for the econometric estimation.

The α_i’s may be thought of as the average value share of input *i* in output value. When β_{ik}’s are zero, the cost function reduces to the Cobb-Douglas form, and the primal output function becomes the familiar $Q_t = A_t K_t^{\alpha_K} L_t^{\alpha_L} E_t^{\alpha_E} M_t^{\alpha_M}$.

The β_{ik}’s are the share elasticities and represent the degree of substitutability among the K,L,E,M inputs. They capture the prices responsiveness of demands for inputs, e.g. how a higher price for energy leads to more demand for capital input. Constant returns to scale in production where the value shares sum to unity and homogeneity restrictions on the cost function (i.e., doubling of all input prices doubles the output price) imply that:

(7) $$\alpha_K + \alpha_L + \alpha_E + \alpha_M = 1$$

$$\sum_i \beta_{ik} = 0 \text{ for each k}$$

That the cost function be symmetric implies that:

(8) $$\beta_{ik} = \beta_{ki}$$

In order to guarantee a well defined interior solution for the model there is also the requirement that the cost function to be “locally concave”. This condition implies that:

(9) $$\mathbf{B} + \mathbf{v}_t \mathbf{v}_t ' - \mathbf{V}_t ,$$

must be non-positive definite at each *t* in the sample period, where $\mathbf{V}_t$ is a diagonal matrix with the value shares along the diagonal.

Turning now to the state variables for technology, if, for example, f_{Kt} is trending upwards then we say that technical change is “capital-using”. Alternatively, if f_{Kt} is trending downwards then technical change is “capital-saving”. When technical change is input-i using that means that higher relative prices for input-i will slow down technical progress. IGEM’s cost function with both β_{ik} and f_{it} allows the separation of price induced changes in input ratios from those that result from changes in technology.

Productivity growth translates into a fall in output price given input prices. The productivity change between *t-1* and *t* is given by:

$$(10) \qquad \Delta T_t = -\sum_{i=1}^{n} \ln P_{it}(f_{it} - f_{i,t-1}) - (f_{pt} - f_{p,t-1})$$

The price technology term, f_{pt}, is non-stationary but the difference, $\Delta f_{pt} = f_{pt} - f_{pt-1}$, is found to be stationary. The state variables f_{it} are stationary. To implement the cost function (4) we express these technology state variables as a vector auto-regression (VAR). Let $\mathbf{F} = (f_k, f_l, f_e, f_m, \Delta f_p)'$ denote the entire vector of stationary state variables. The transition equations are assumed to be governed by:

$$(11) \qquad \mathbf{F}_t = \mathbf{\Phi F}_{t-1} + u_t$$

where u_t is a random variable with mean zero and $\mathbf{\Phi}$ is a matrix of estimated coefficients of the first-order VAR.

The goal in choosing the above state space representation of technology is to allow in IGEM both a flexible representation of complex behavior in the sample period and a feasible but controlled representation of technical change for the projection period. Specifically, IGEM is a model with infinitely lived households in consumption and, so, requires simulation to a steady-state (i.e., zero-growth) solution in all model inputs and outputs. In turn, this requires that trends in factor biases and neutral technical change, projected from observed history, transition to constants in steady state. This transition is presumed to begin after 25 to 30 years and is completed within another 25 to 30 years, reflecting a conservative approach toward a distant and very uncertain future.

B1.2.3. Lower tiers production function for intermediate inputs

In the subsequent stages of production, the energy and material aggregates are allocated to the *m* individual commodities. To repeat equation (2) for the second stage:

$$(12)\qquad E_j = E(X_{3j,}X_{4j}, X_{16j}, X_{30j}, X_{31j}); \qquad M_j = M(X_{1j},...X_{35j}, X_{Nj})$$

where the components of the non-energy materials (M) aggregate are every other commodity in Table B1 except for the five energy commodities. Also included in M is non-competing imports which is a "commodity" not produced by any domestic industry. It is denoted as X_N.

The demand for these detailed commodities by each industry *j* also is derived from a translog cost function. These sub-tier cost functions have a simpler form than equation (4) in that they do not have the technology terms. This is due to the requirements of consistent aggregation. To illustrate these sub-tier functions, the cost function for the energy aggregate is written as:

$$(13)\qquad \ln P_{Et} = \alpha_0 + \sum_{i=\{3,4,16,30,31\}} \alpha_i \ln P_{it}^X + \tfrac{1}{2}\sum_{i,k} \beta_{ik} \ln P_{it}^X \ln P_{kt}^X$$

while the share equation for the first component of aggregate energy (coal mining) is:

$$(14)\qquad v_3 = \frac{P_3^X X_3}{P_E E} = \alpha_3 + \sum_{k=3,4,16,30,31} \beta_{3k} \ln P_k^X \ ,$$

Again, the β_{ik} 's are share elasticities representing the degree of substitution among the 5 types of energy, and the α 's are the average input value shares.

The long list of items in the materials aggregate, M(.), requires that it too be arranged in a multi-stage manner. The entire tier structure for producer behavior in each industry is given in Table B2. The M(.) aggregate consist for 5 sub-aggregates – Construction, Agricultural materials, Metallic materials, Nonmetallic materials and Services materials. These sub-aggregates, in turn, are functions of other groups and so on until all the *m* commodities are accounted for. Each node in the tier structure employs a cost equation as written by a generalized equation (13).

Table B2. Tier structure of industry production function.

	Symbol	Name	Components
1	Q	Gross output	capital, labor, energy, materials Q=f(K,L,E,M)
2	E	Energy	coal mining, petroleum & gas mining, petroleum refining, electric utilties, gas utilities E=f(X3,X4,X16,X30,X31)
3	M	Materials (nonenergy)	Construction, Agriculture Mat, Metallic Mat, Nonmetallic Mat, Services Mat M=f(X6,MA,MM,MN,MS)
4	MA	Agriculture materials	Agriculture, Food manuf, Tobacco, Textile-apparel, Wood-paper MA=f(X1,X7,X8,TA,WP)
5	MM	Metallic Materials	Fab-other metals, Machinery mat, Equipment MM=f(FM,MC,EQ)
6	MN	Nonmetallic Materials	Nonmetal mining, Chemicals, Rubber, Stone, Misc manuf MN=f(X5,X15,X17,X19,X27)
7	MS	Services Materials	Transportation, Trade, FIRE, Services, OS MS=f(X28,X32,X33,X34,OS)
8	TA	Textile-apparel	Textiles, Apparel, Leather TA=f(X9,X10,X18)
9	WP	Wood-paper	Lumber-wood, Furniture, Paper, Printing WP=f(X11,X12,X13,X14)
10	OS	Other services	Communications, Govt. enterprises, NC imports OS=f(X29,X35,X_N)
11	FM	Fab-other Metals	Metal mining, Primary metals, Fabricated metals FM=f(X2,X20,X21)
12	MC	Machinery materials	Ind. Machinery, Electric Machinery MC=f(X22,X23)
13	EQ	Equipment	Motor vehicles, Other transp equip, Instruments EQ=f(X24,X25,X26)

B1.2.4. Relation between commodities and industries, and output taxes.

One of the taxes that are explicitly identified in the model is production (or sales) taxes. This introduces a wedge between the seller and buyer prices. Denoting the buyer price of industry output by $P_{QT,j}$:

(15) $$P_{QT,j} = (1+tt_j)P_{Q,j}$$

Each industry makes a primary commodity and many make secondary products that are the primary output of some other industry. In the *make* matrix the M_{ji} element represents the value of the *i*th commodity produced by industry *j*. Thus, the *i*th column of the *make* matrix indicates which industries contribute to the *i*th commodity, while the *j*th row shows which commodities are made by industry *j*.

The value of industry *j* output is $P_{QT,j}Q_j$; let the price, quantity and value of commodity *i* be denoted by, P_{Ci}, QC_i, VQC_i respectively, all from the buyer's point of view. For column *i* of the make matrix, let the shares contributed by the various industries to that commodity in the base year be denoted:

(16) $$m_{ji} = \frac{M_{ji,t=T}}{VQC_{i,t=T}}; \qquad \sum_j m_{ji} = 1$$

For row *j*, let the shares of the output of industry *j* be allocated to the various commodities be denoted:

(17) $$m_{ji}^{row} = \frac{M_{ji,t=T}}{P_{QT,j}Q_{j,t=T}}; \qquad \sum_i m_{ji}^{row} = 1$$

These shares are assumed fixed for all periods after the base year. Equivalently, the production function of commodities is a simple Cobb-Douglas aggregate of the output from the various industries where the component weights are these base year shares. Thus, the price of domestic commodity *i* is given as:

(18) $$P_{Ci} = P_{Q1}^{m_{1i}} \ldots P_{Qm}^{m_{mi}} \qquad \text{for i=1,2,....m}$$

The values and quantities then are given by:

(19) $$VQC_{it} = \sum_j m_{ji}^{row} P_{Qjt} Q_{Yjt} \qquad \text{for i=1,2,....m}$$

(20) $$QC_i = \frac{VQC_i}{P_{Ci}}$$

B1.3. Household model

To capture differences among households, the household sector is subdivided into demographic groups including region of residence. Each household is treated as a consuming unit, i.e. it is the unit maximizing some utility function over all commodities in IGEM, including leisure.

As currently specified, demographic differences in IGEM are limited to the allocation of commodity consumption. These differences do not enter the allocation of time between work and leisure nor do they enter the allocation of income between consumption and saving. IGEM's household model thus has three stages. At the first stage, lifetime income is allocated to consumption and saving in each period. This consumption consists of commodities and leisure and is referred to as "full consumption". In the second stage, full consumption is allocated to total goods and services and leisure. In the third stage, total goods and services are allocated to IGEM's various energy and non-energy commodities. This third stage is actually a series of stages and is where the detailed demographic information appears.

B1.3.1. Notation

F_t	quantity of full consumption
C_t	quantity of aggregate goods consumption
L_t^{leis}	quantity of aggregate leisure
LS_t	quantity of aggregate labor supply
$\overline{L}_t$	quantity of aggregate time endowment
KS_t	quantity of aggregate capital stock at end of period t
n_t	growth rate of population index
P_t^F, P_t^C, P_t^{leis}	price of F_t, C_t and L_t^{leis}
P_t^L	price of labor to employer, economy average
P_t^K	price of capital (rental rate), economy average
r_t	rate of return between t-1 and t
Y_t^{hh}	household disposable income
S_t^{hh}	household savings

B1.3.2. Household model 1st stage (intertemporal optimization)

At this level, the aggregate household maximizes an additively separable inter-temporal utility function:

$$(21) \qquad U = \sum_{t=0}^{\infty} N_0 \prod_{s=1}^{t} \left(\frac{1+n_s}{1+\rho} \right) \ln F_t$$

subject to a lifetime budget constraint:

$$(22) \qquad W_0^F \geq \sum_{t=0}^{\infty} \left(\prod_{s=1}^{t} \frac{1}{1+r_s} \right) P_t^F F_t$$

where F_t is the per capita full consumption in period *t*, ρ is the econometrically estimated rate of time preference, N_0 is the initial population, and n_s is the population growth rate in period *s*. W_0^F is the aggregate household's "full wealth" at time 0, P_t^F is the price of full consumption and r_s is the rate of return between *s-1* and *s* (i.e., the spot market interest rate). The term "full wealth" refers to the present value of future earnings from the supply of tangible assets and labor, plus transfers from the government and imputations for the value of leisure. Tangible assets include domestic physical capital, government bonds and net foreign assets.

Equations (21) and (22) are common to Cass-Koopmans type growth models occurring in standard macroeconomics textbooks (e.g. Barro and Sala-i-Martin 1995). Inter-temporal optimality is expressed in a so-called Euler equation and requires that:

$$(23) \qquad \frac{F_t}{F_{t-1}} = \frac{(1+n_t)(1+r_t)}{1+\rho} \frac{P_{t-1}^F}{P_t^F}$$

The Euler equation is forward-looking, so that the current level of full consumption incorporates expectations about all future prices and discount rates. The solution in IGEM includes this forward-looking relationship in every period. The future prices and discount rates determined by the model enter full consumption for earlier periods through the assumption of perfect foresight (or rational expectations if there was uncertainty in the model). The value of full consumption in any period is the key element in deriving household saving in that period.

B1.3.3. Household model 2nd stage (goods and leisure)

Once each period's full consumption is determined, it is subsequently divided into aggregate personal consumption expenditures (commodities) and leisure time. The determination of leisure is also the determination of labor supply. Full consumption at time t is viewed as a utility function of aggregate commodities (C_t) and leisure (L_t^{leis}) at t:

(24) $F_t = F(C_t, L_t^{leis})$

and the value of full consumption is the sum of the values of goods consumption and leisure:

(25) $P_t^F F_t = P_t^C C_t + P_t^{leis} L_t^{leis}$

For this stage of the household model, it is assumed that the utility function is homothetic, i.e. the income elasticities for goods and leisure are one. The producer model used the cost dual instead of the direct production function. Here again, it more convenient to use the indirect utility function, $V_t^F = V(P_t^C, P_t^{leis}, Y_t^{hh})$, to derive the demand for aggregate consumption and leisure. The translog form of the indirect utility function under the assumption of homotheticity results in the following constant returns to scale "cost function" for the price of full consumption[14]:

(26) $\ln P^F = \alpha_c \ln P^C + \alpha_{leis} \ln P^{leis} + \frac{1}{2} \sum_{i,j=\{C.leis\}} \beta_{ij} \ln P^i \ln P^j$

The demand for goods consumption and leisure is derived in a manner identical to that for input demands in the producer model (equation 6):

(27) $\frac{P^C C}{P^F F} = \alpha_C + \beta_{cc} \ln P^C + \beta_{cl} \ln P^{leis}$

Given the demand for leisure, the quantity of labor supply, *LS*, is the exogenous time endowment minus leisure:

(28) $LS_t = \overline{L}_t - L_t^{leis}$

The time endowment $\overline{L}_t$ is aggregated from population data by detailed demographic groups and using wage rates as weights.

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[14] This indirect utility function for full consumption is first used in Jorgenson and Yun (1986)..

In equation (22) for the lifetime budget constraint, W_0^F represents the present value of the stream of household full income, that is, tangible income plus the imputation for leisure value. Household tangible income is the sum of after-tax labor income, capital income, interest income from government bonds (B^G), interest income from net foreign assets (B^*), and transfers from the government (G^{hh}):

(29) $$Y_t^{hh} = (1-tl)P_t^L LS_t + (1-tk)P_t^K KS_{t-1} + i(B_{t-1}^G) + i(B_{t-1}^*) + G_t^{hh} - twP_{t-1}^{KS} KS_{t-1}$$

where *KS* is the stock of capital owned by households, P_t^K is the rental price of aggregate capital, and *tl* and *tk* are tax rates on labor and capital income respectively. *tw* is the wealth (estate) tax put on the value of capital stock whose price is P^{KS}.

The difference between the price of leisure and the wage paid by employers is the labor tax:

(30) $$P^{leis} = (1-tl)P^L$$

The capital price (P^K) and tax (*tk*) has a similar interpretation[15].

Private household saving then is simply tangible income less consumption, non-tax payments to the government and transfers to rest-of-the-world:

(31) $$S_t^{hh} = Y_t^{hh} - P_t^C C_t - R_t^N - H_t^{row}$$

B1.3.4. Household model 3rd stage

Once the total value of spending on commodities is determined in the second stage, it then is allocated to all IGEM's available. The allocation of aggregate consumption is done according to the household demand model in Jorgenson and Slesnick (1987). Households are divided into various demographic types by income (expenditure) class, age, sex and race of head, family size, and type and region of residence, and the demands for goods and services are indexed by household types. Total personal consumption is the aggregate over all the household types.

In the producer model, the 35 intermediate inputs entered via a tier structure with the top tier written as *Q=f(K,L,E,M)*. The household commodity model is similarly a

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[15] Further features about the actual tax system is left out of this description to avoid too much unimportant detail. These include the property tax, estate tax and non-tax payments. These are, however, included in the accounts of the economy and in the actual code of the model.

function of 35 items, and the top tier is a function of five commodity groups – energy, food, non-durables, capital services, and services. Let the prices of these groups be denoted P_{EN}, P_{FD}, P_{ND}, P_K, P_{SV}, and the value of total expenditures by household *k* be M_k:

$$M_k = P_{EN}C^k_{EN} + P_{FD}C^k_{FD} + P_{ND}C^k_{ND} + P_K C^k_K + P_{SV}C^k_{SV} \tag{32}$$

The indirect utility function for household *k*, $V(P_{EN},..P_{SV}, M_k; A_k)$, is written in translog form as:

$$\ln V_k = \sum_i \alpha_i \ln\frac{P_i}{M_k} + \tfrac{1}{2}\sum_{i,j}\beta_{ij}\ln\frac{P_i}{M_k}\ln\frac{P_j}{M_k} + \sum_i \beta_{Ai}A_k \ln\frac{P_i}{M_k} \tag{33}$$

$$i, j = \{EN, FD, ND, K, SV\}$$

where A_k is a vector of demographic dummies and α_i, β_{ij} and β_{Ai} are parameters that are estimated from historical data.

In order to derive an aggregate demand function, restrictions are imposed on the parameters as explained in Jorgenson and Slesnick (1987). With these restrictions the share demand equations are derived as:

$$w^k = \frac{\alpha + \mathbf{B}\ln p - \mathbf{B}\boldsymbol{\iota}\ln M_k + \beta_A A_k}{-1 + \boldsymbol{\iota}\mathbf{B}\ln p} \tag{34}$$

where w^k is the vector of shares, $(P_{EN}C^k_{EN}/M_k,..., P_{SV}C^k_{SV}/M_k)$, and p is the vector of the 5 prices. $\mathbf{B} = [\beta_{ij}]$ and $\boldsymbol{\iota}$ is a vector of 1's. The aggregate demand for these 5 commodity groups is the sum over all households:

$$w = \frac{\sum_k w^k M_k}{\sum_k M_k} = \frac{1}{-1 + \boldsymbol{\iota}\mathbf{B}\ln p}[\alpha + \mathbf{B}\ln p - \mathbf{B}\boldsymbol{\iota}\sum_k \frac{M_k \ln M_k}{M} + \beta_A \sum_k \frac{M_k A_k}{M}] \tag{35}$$

The total economy spending by all households is the value of consumption from the second stage, eqs (25) and (27):

$$M_t = \sum_k M_{kt} = P^C_t C_t \tag{36}$$

and the aggregate share vector is:

$$w = (P_{EN}C_{EN}/M,..., P_{SV}C_{SV}/M)' \tag{37}$$

The demands for the five commodity groups, $C_{EN}, C_{FD}, C_{ND}, C_K, C_{SV}$, are allocated to the individual commodities identified in the model. These groups are based on the definitions in the Consumer Expenditure Surveys and reconciled with the categories in the Personal Consumption Expenditures (PCE) in the National Accounts. These detailed categories in the National PCE for 35 items are given in Table B3 and, below, their prices and quantities are denoted by P_i^N and C_i^N. The tier structure allocating the five consumption groups to these detailed C_i^N is organized like that for the production function and is given in Table B4. There is a total of 16 sub-tier functions and they are written in a manner identical to the example in equation (13) and (14) for the production energy sub-tier, that is, the price of energy for the household is a function of the prices of gasoline, fuel oil, coal, electricity, and gas:

$$(38) \qquad P_{EN} = f(P_6^N, P_7^N, P_8^N, P_{18}^N, P_{19}^N)$$

Using these sub-tier cost functions yields the aggregate demands for all 35 NIPA-PCE items { C_i^N }.

Table B3. Commodities classified by NIPA Personal Consumption Expenditures

	IGEM classes	NIPA PCE classes
1	Food	Food purchased for off-premise consumption
2	Meals	Purchased Meals and Beverages
3	Meals-Employees	Food furnished employees incl. farms
4	Shoes	Shoes
5	Clothing	Clothing and accesories except shoes; Clothing military
6	Gasoline	Gasoline and Oil
7	Coal	Fuel Oil and Coal
8	Fuel	Fuel Oil and Coal
9	Tobacco	Tobacco products
10	Cleaning	Cleaning and misc. household supplies and paper
11	Furnishings	Semi-durable house furnishings
12	Drugs	Drug preparations and sundries
13	Toys	Nondurable toys and sport supplies
14	Stationery	Stationery and writing supplies
15	Imports	Expenditures abroad by US residents
16	Reading	Magazines, newspapers; Flowers and potted plants
17	Rental	Tenant-occupied nonfarm; Farm dwellings; Housing-other
18	Electricity	Electricity
19	Gas	Gas
20	Water	Water and sanitary services
21	Communications	Telephone and Telegraph
22	Labor	Domestic service
23	Other household	Household Operation- Other
24	Own transportation	User-operated transportation services
25	Transportation	Purchased local transportation; Intercity transportion
26	Medical Services	Physicians; Dentists; Other professional; Hospitals & homes
27	Health Insurance	Health Insurance
28	Personal services	Cleaning, storage, repair; Cothing-Other; Barbershops etc.
29	Financial services	Brokerage; Bank service; Services without payment;
		Expense of life insurance and pension plans
30	Other services	Legal services, Funeral & burial, Personal business-other
31	Recreation	Repair; Admissions to spectator amusements; Clubs;
		Commercial participant amusements; pari-mutuel; Recreation-other
32	Education Inst.	Education and research; Religious and welfare activities
33	Foreign Travel	Foreign Travel by US residents
34	Owner maintenance	Imputations for maintenance of owner occupied housing
35	Durables	Imputed rental value from all durable classes:
		Jewelry and watches; Furniture; ..... Video and audio goods

Note: NIPA-PCE classes are those given in the National Accounts in the annual *Survey of Current Business*, e.g. (SCB August 2001, Table 2.4).

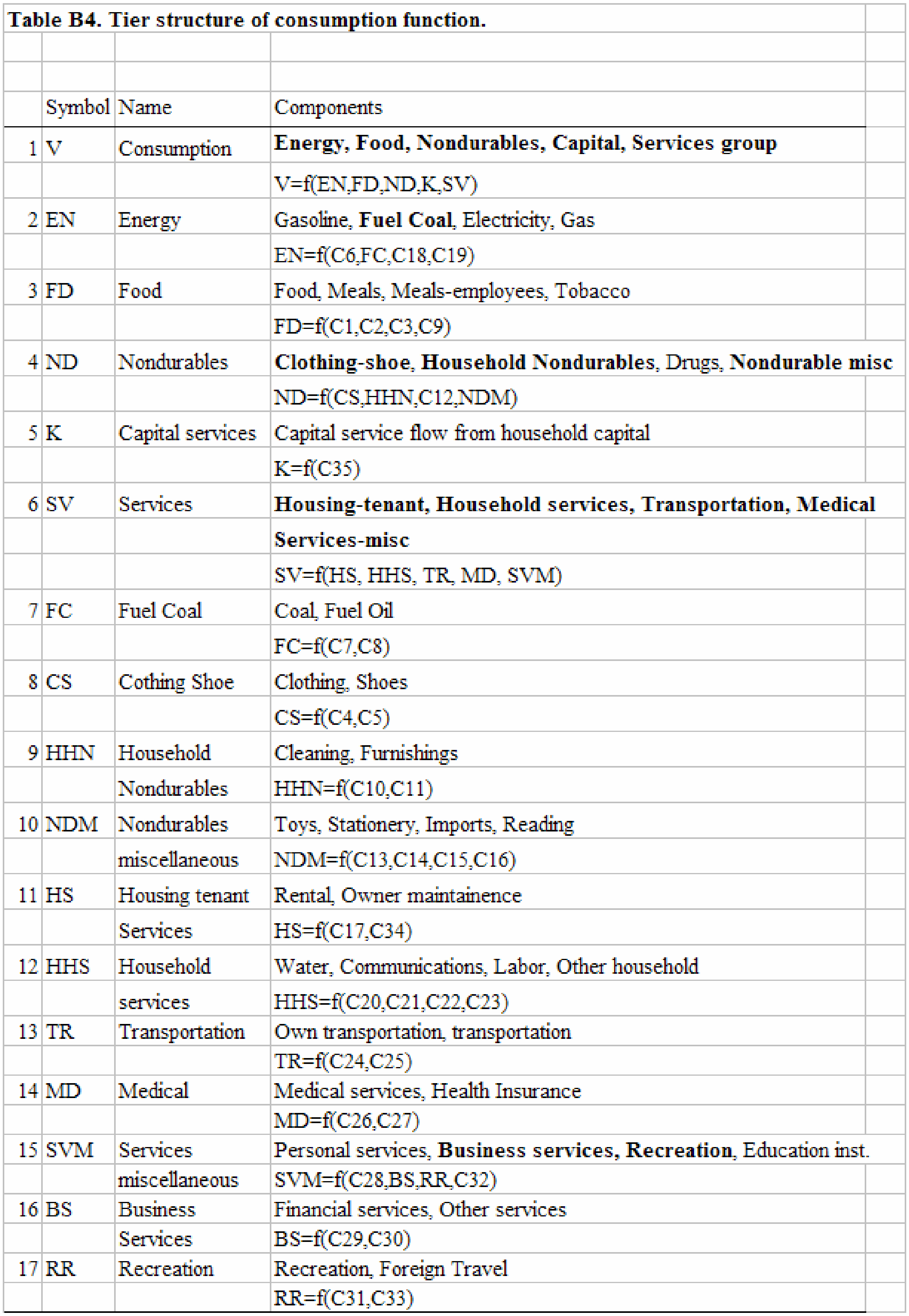

Table B4. Tier structure of consumption function.

	Symbol	Name	Components
1	V	Consumption	**Energy, Food, Nondurables, Capital, Services group**
			V=f(EN,FD,ND,K,SV)
2	EN	Energy	Gasoline, **Fuel Coal**, Electricity, Gas
			EN=f(C6,FC,C18,C19)
3	FD	Food	Food, Meals, Meals-employees, Tobacco
			FD=f(C1,C2,C3,C9)
4	ND	Nondurables	**Clothing-shoe**, **Household Nondurables**, Drugs, **Nondurable misc**
			ND=f(CS,HHN,C12,NDM)
5	K	Capital services	Capital service flow from household capital
			K=f(C35)
6	SV	Services	**Housing-tenant, Household services, Transportation, Medical**
			Services-misc
			SV=f(HS, HHS, TR, MD, SVM)
7	FC	Fuel Coal	Coal, Fuel Oil
			FC=f(C7,C8)
8	CS	Cothing Shoe	Clothing, Shoes
			CS=f(C4,C5)
9	HHN	Household	Cleaning, Furnishings
		Nondurables	HHN=f(C10,C11)
10	NDM	Nondurables	Toys, Stationery, Imports, Reading
		miscellaneous	NDM=f(C13,C14,C15,C16)
11	HS	Housing tenant	Rental, Owner maintainence
		Services	HS=f(C17,C34)
12	HHS	Household	Water, Communications, Labor, Other household
		services	HHS=f(C20,C21,C22,C23)
13	TR	Transportation	Own transportation, transportation
			TR=f(C24,C25)
14	MD	Medical	Medical services, Health Insurance
			MD=f(C26,C27)
15	SVM	Services	Personal services, **Business services, Recreation**, Education inst.
		miscellaneous	SVM=f(C28,BS,RR,C32)
16	BS	Business	Financial services, Other services
		Services	BS=f(C29,C30)
17	RR	Recreation	Recreation, Foreign Travel
			RR=f(C31,C33)

The commodity outputs from the producer models are classified by input-output categories. The official benchmark IO tables from the Bureau of Economic Analysis come with bridge tables that link the NIPA-PCE categories to the IO classification. For example, they show how "nondurable toys and sport supplies" (item 13 in Table B3) is made up of deliveries from Chemicals, Miscellaneous Manufacturing, Trade, Transportation, etc. Using this bridge table, denoted $\mathbf{H} = [H_{ij}]$, gives consumer demands in terms of their IO classification:

$$(39) \qquad P_i^X C_i = \sum_j H_{ij} P_j^N C_j^N$$

B1.4. Investment and the cost of capital

The primary factors of production in this model are capital and labor. Capital here includes structures, producer's equipment, land, inventories, and consumer durables. This differs from the official investment in the National Income and Product Accounts (NIPA) which records consumer durables as part of Personal Consumption Expenditures[16]. Capital here is assumed to be the capital owned by the private sector. Government owned capital is accounted for separately.

Capital is mobile and moves costlessly from one industry to another within any period. Investment goods are converted costlessly into capital stock; there are no installation or adjustment costs. These assumptions mean that producer optimization reduces to minimizing the cost of production in period *t* (equation 4) without the necessity of considering future prices. Also, with an aggregate household owning all the capital with perfect foresight, the saving decision is the investment decision[17]. However, it is important to present the savings-investment decision in a manner that clarifies the economy's cost of capital, a key determinant of overall growth.

The owner of the stock of capital may be thought of as choosing the path of investment by maximizing the stream of capital income subject to a capital accumulation constraint. Let KS_t denote the aggregate capital stock at the end of period *t*, which is to be

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[16] Land is in the "fixed, non-reproducible" asset category, and is not part of Investment in GDP (land is transferred, not produced). The rental from land is, of course, included in the income side of GDP.

[17] Other types of growth models with adjustment costs of investment would have a distinct investment function, i.e. distinct from the household savings function.

distinguished from the flow of capital services K_{jt} in the industry production function equation (2). Let P_t^K denote the rental price of a unit of this stock, the model maximizes the discounted rental income net of purchases of aggregate new investment:

$$(40) \quad \text{Max} \quad \sum_{t=0}^{\infty} \frac{(1-tk)P_t^K KS_{t-1} - P_t^I I_t^a}{\prod_{s=0}^{t}(1+r_s)}$$

$$(41) \quad \text{s.t.} \qquad KS_t = (1-\delta)KS_{t-1} + I_t^a$$

The after tax capital income term, $(1-tk)P_t^K KS_{t-1}$, is the same as that in the household income equation (29), and the discount rate r_s is the same as that in the Euler equation (23). I_t^a is the quantity of aggregate investment and P_t^I is its price. (Certain tax details in the model, such as depreciation allowances, are not represented above so as to focus on the model's main points.)

Aggregate investment is actually a basket of commodities ranging from computers to structures. This basket changed substantially in the sample period. An index of the quality of aggregate investment, ψ_t^I, is employed to keep track of the changing composition. Accordingly, Eq (41) is actually written as:

$$(42) \quad KS_t = (1-\delta)KS_{t-1} + \psi_t^I I_t^a .$$

This refinement is ignored below to keep the description simple but is used in the actual model.

The solution of the maximization problem gives the Euler equation:

$$(43) \quad (1+r_t)P_{t-1}^I = (1-tk)P_t^K + (1-\delta)P_t^I$$

There is a simple interpretation of this equation. If P_{t-1}^I dollars were put in a bank in period *t-1* it would earn a gross return of $(1+r_t)P_{t-1}^I$ at *t*. On the other hand, if P_{t-1}^I dollars were used to buy one unit of capital goods it would collect rent for one period, and the depreciated capital would be worth $(1-\delta)P_t^I$ in period *t* prices.

The assumption that there are no installation costs means that new investment goods are linearly substitutable for old capital; that is, the price of capital stock is equal to the price of aggregate investment:

$$(44) \quad P_t^{KS} = P_t^I$$

Equations (40-44) say that, in equilibrium, the price of one unit of capital stock (P^{KS}) is the present value of the discounted stream of rental payments, or capital service flows (P^{K})[18]. In the perfect foresight equilibrium path of the solution, the capital rental prices, interest rates and stock prices for each period are such that equation (43) holds. This incorporates the forward-looking dynamics of asset pricing into the model of inter-temporal equilibrium. There is also the backward-looking asset accumulation equation (41).

With equation (44) the Euler equation (43) can be rewritten as the well-known cost of capital equation (Jorgenson 1963):

$$(45) \qquad P_t^K = \frac{1}{(1-tk)}[(r_t - \pi_t) + \delta(1+\pi_t)]P_{t-1}^{KS}$$

where $\pi_t = (P_t^{KS} - P_{t-1}^{KS}) / P_{t-1}^{KS}$ is the asset inflation rate. This rental price of aggregate capital is the endogenous price that equates the demand for capital by the 35 industries and households with the supply given by KS_{t-1}. When property taxes (taxes based on the value of assets) are included the cost of capital equation becomes:

$$(45') \qquad P_t^K = [\frac{1}{(1-tk)}((r_t - \pi_t) + \delta(1+\pi_t)) + tp]P_{t-1}^{KS}$$

The quantity of total investment demanded by the household/investor is I_t^a when the price is $P_t^{KS} = P_t^I$. This aggregate demand for producer durables, consumer durables and inventories is allocated as demand for the *m* individual commodities − Construction of new structures, Machinery, Electric Machinery, Instruments, etc. − by means of a simple production function:

$$(46) \qquad I^a = I(I_1, I_2, ..., I_m)$$

The *m* types of commodity inputs are the same set as the commodities demanded by the household and producers. In the same way that demands for intermediate inputs are derived from a nested tier of translog price functions in equations (12-14) and Table B2, investment commodity demands are derived from a nested structure of investment price

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[18] In a model with uncertainty, this would be stated as, "the present value of the expected stream discounted at risk adjusted rates...".

functions[19]. (The details are in Appendix E of Ho (1989)). The price of aggregate investment is thus a function of the prices of commodities:

$$(47) \qquad P^I = P(P_1^X, P_2^X, ..., P_m^X)$$

The value of total investment is thus:

$$(48) \qquad P^I I^a = \sum_{i=1}^{m} P_i^X I_i$$

The value, $P_i^X I_i$, is the *i*th row of the Investment column in the *use* table (part of the total final demand *F* in Figure B2).

In summary, capital formation is the outcome of inter-temporal optimization. Decisions today are based on expectations of future prices and rates of return, including the world prices of energy. Policies, announced today, that change future rules affect today's decisions.

B1.5. Government

The government plays several important roles in IGEM. Government spending affects welfare directly (e.g. through transfer payments) and, indirectly, through public capital that improves private sector productivity. Taxes introduce wedges between buyers and sellers and distort the allocation of resources. IGEM does not incorporate a sophisticated model for public goods and taxation (e.g. median voter models) but instead treats the government sectors in a relatively simple fashion. They are not regarded as optimizing agents. Tax rates and the overall budget deficit are set exogenously as specified by current law and "officially" projected trends conditioned by it. Expenditures on individual commodities are set as simple share functions.

Following the National Income and Product Accounts, general government purchases are distinguished from government enterprises. The latter are treated as part of the business sector; it is industry number 35. This section considers only the purchases of finished goods and services by federal, state and local governments. The accounting system developed in Jorgenson (1980) regards the social insurance system as internal to

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[19] In the household sub-model in section 3 the demand for individual commodities is specified with a rich consumption function including demographics and estimated with Consumer Expenditure Survey data. There is no corresponding theory of investment commodity demand.

the household sector; social security taxes are regarded as private savings and the insurance trust funds regarded like private assets.

B1.5.1. General Government Revenues and Expenditures

The taxes that are explicitly recognized are sales taxes, import tariffs, the capital income tax, labor income taxes, the property tax, and the wealth (estate) tax. Sales taxes tt_j were defined in equation (15), the labor tax tl was used in equation (29) and (30), and the capital income tax tk was used in equation (29) and (45). The property tax appears in the cost of capital equation (45), while the wealth tax is in equation (29). Tariffs, tr, are described later in equation (55). There is also an item called non-tax receipts that includes various fees charged by the government (denoted R^N) appearing in equation (31). The final revenue item is the profit or surplus from government enterprises (R^{ent}).

These tax formulations are an abstraction of the complex actual system that includes depreciation allowances, tax credits, “alternative minimum tax”, etc. The tax rates are developed from historical data in a manner that replicates actual revenues; they are close to, but not identical with statutory rates[20]. For labor income, there is also the distinction between marginal and average tax rates. For example, in the definition of the price of leisure (equation 30) the labor tax rate is the marginal rate.

Government expenditures fall into 4 major categories − goods and services from the private sector, transfers to households and foreigners, interest payment on debt to households and foreigners, and subsidies. The first three are denoted by V^{GG}, $G^{hh}+G^{row}$ and $i(B^G_{t-1})+i(B^{G*}_{t-1})$. Subsidies are regarded as negative sales taxes and included in the calculation of tt_j in equation (15). Transfers and interest payments are set exogenously, scaled to preliminary projections of the economy and population and aligned with the “official” forecasts from the Congressional Budget Office (CBO 2003, 2004). The total spending on commodities (including labor and capital) is V^{GG}, and this is allocated to the individual commodities using shares from the base year:

$$(49) \qquad P^X_{it}G_{it}=\alpha^G_i V^{GG}_t \qquad P^L_{Gt}L_{Gt}=\alpha^G_L V^{GG}_t \qquad P^K_{Gt}K_{Gt}=\alpha^G_K V^{GG}_t$$

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[20] For example, the tax paid on labor income is part of personal income taxes and follow the complex federal and state government income tax rules.

The value, $P_i^X G_i$, is the *i*th row of the Government column in the *use* table in Figure B2.

B1.5.2. Government Deficits and Debts

The total revenue of the government is thus:

$$Rev = \sum_j tt_j P_{Y,j} Y_j + \sum_i tr_i P_{M,i} M_i + tkP^K KS_{t-1} + tlP^L LS + tpP^{KS} KS_{t-1} + twP^{KS} KS_{t-1} + R^N + R^{ent} \tag{50}$$

Total government expenditures are:

$$Exp = V^{GG} + G^{hh} + G^{row} + i(B_{t-1}^G) + i(B_{t-1}^{G*}) \tag{51}$$

In the National Income and Product Accounts (NIPA) there is a distinction made between current expenditures and investment spending, and between current receipts and capital transfers. This results in a "current deficit" that is distinct from "net borrowing requirement". No such distinction is made in IGEM. Here, the public deficit of the government is total outlays less total revenues, a concept similar to the official "net borrowing requirement." Denoting the deficit by ΔG:

$$\Delta G = Exp - Rev \tag{52}$$

The difference between IGEM's accounting of the deficit and NIPA is the treatment of the social insurance surplus. The deficit in IGEM is, conceptually, the NIPA borrowing requirement plus the social insurance fund surplus.

These deficits add to the public debt. Total government debt is separated into that held by US residents and that held by foreigners but in IGEM only the net total debt, $B^G + B^{G*}$ matters. Notationally:

$$B_t^G + B_t^{G*} = B_{t-1}^G + B_{t-1}^{G*} + \Delta G_t + \delta^{BG} \tag{53}$$

The official accounts of the stock of debt[21] unfortunately are not reconciled with the official deficits given in NIPA. There is, therefore, a discrepancy term, δ^{BG}, in the above equation. The accounting in equation (53) is in book value terms; there is also an exogenous capital gains term that is omitted.

To summarize, tax rates are set exogenously (and are not necessarily constant in the forecast period), and as is the overall deficit of federal, state and local government.

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[21] These are given in the *Flow of Funds, Assets and Liabilities* published by the Federal Reserve Bank.

The model generates economic activity and, hence, tax revenues are endogenous. Government transfers and net interest are set exogenously and, so, the remaining item in equation (51), total general government spending on goods (V^{GG}) is determined residually.

B1.6. Rest of the world (exports, imports and total supply)

IGEM is a national, one-country model, which is to say that the supply of goods from the rest of the world (ROW) is not modeled explicitly for each commodity. Similarly the demand for U.S. exports is not driven by endogenous world growth rates as is done in multi-country models. IGEM follows the treatment that is standard in one-country models, that is, imports and domestic output are regarded as imperfect substitutes where the elasticities of substitution are not infinite. This is often referred to as the "Armington" assumption and is reasonable at IGEM's level of aggregation[22]. It is also assumed that U.S. demand is not sufficient to change world relative prices.

The total supply of commodity *i* is an aggregate of the domestic and imported varieties:

$$(54) \qquad XS_{it} = XS(QC_i, M_i, t)$$

The domestic commodity supply is given in equation (20), while M_i denotes the quantity of competitive imports[23]. This is to be distinguished from non-competing imports described in section B1.2. The price of competitive imports is the world price multiplied by an "exchange rate" (*e*), plus tariffs (*tr*):

$$(55) \qquad P_{M,it} = (1 + tr_{it}) e_t P^{*}_{M,it}$$

e_t is technically the world relative price and its role will be made clear after the discussion of the current account balance below.

The supply function is similar to the production model given in equations (1)-(6). The demand for domestic and imported varieties is derived from a translog price function for the total supply price:

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[22] That is, while one may regard the imports of steel of a particular type as perfectly substitutable, the output of the entire Primary Metals sector is a basket of many commodities and would have an estimated elasticity that is quite small.

[23] The notation M_j denoted above the inputs of non-energy materials into the industry production function. The distinction here from M_i as commodity imports should be clear from the context.

(56) $$\ln P_{it}^{X} = \alpha_{ct} \ln P_{C,it} + \alpha_{mt} \ln P_{M,it} + \tfrac{1}{2} \sum_{j,k \in \{C,M\}} \beta_{jk} \ln P_{j,it} \ln P_{k,it}$$

(57) $$\frac{P_{M,it} M_{it}}{P_{it}^{X} XS_{it}} = \alpha_{mt} + \beta_{MM} \ln \frac{P_{M,it}}{P_{C,it}}$$

(58) $$P_{it}^{X} XS_{it} = P_{C,it} QC_{it} + P_{M,it} M_{it}$$

It should be noted that there now is a closed loop in the flow of commodities. Producers purchase intermediate inputs at price P_i^X and sell output at price $P_{QT,j}$. Prices of intermediates, P_{it}^X, are the prices given in equation (56), that is, the prices of total supply. It is assumed that all buyers buy the same bundle of domestic and imported varieties for each type *i*.

Imports into the U.S. have been rising rapidly during the sample period, not just in absolute terms but as a share of domestic output. As explained in Ho and Jorgenson (1994), this is modeled by indexing the parameter α_m in equations (56 and 57) by time, allowing the share to rise exogenously over time. The β_{MM} coefficient is the share elasticity and, for most goods, is a fairly elastic parameter.

As noted in section B1.2, one of the inputs into the industry production functions is non-competing imports. These are goods that do not have close U.S. substitutes, e.g. coffee. The demand for these are derived in the nested structure of the production function, the value of such imports by industry *j* is $P_{NC,j} X_{Nj}$.

The demand for U.S. exports should depend on world prices and world incomes. Since these are not modeled endogenously, IGEM begins with an exogenous projection of world incomes and demands (X_{it0}^{x}). It is assumed that the world price of commodity *i* relative to commodity *k*, ($P_{C,i}^{*} / P_{C,k}^{*}$), is not affected by U.S. market outcomes. With these projections, the export demand for commodity *i* is written as a function of domestic prices and the effective world price $eP_{C,i}^{*}$. Normalizing units such that the world price is 1 yields:

(59) $$X_{it}^{x} = X_{it0}^{x} \left(\frac{P_{C,it}}{e_t} \right)^{\eta_i}$$

The estimates of the export elasticity coefficient are also reported in Ho and Jorgenson (1994).

The current account balance is exports minus both types of imports, plus exogenous net interest payments and transfers:

$$(60) \qquad CA_t = \sum_i P_{C,i} X_i^x - \sum_i e_t P_{Mi}^* M_i - \sum_j e P_{NC,j}^* X_{Nj} + i(B_{t-1}^*) - i(B_{t-1}^{G*}) - H_t^{row} - G_t^{row}$$

This current account surplus adds to the stock of net U.S. foreign assets, which is equivalent to net private claims on ROW minus net government debt to the ROW:

$$(61) \qquad B_t^* - B_t^{G*} = B_{t-1}^* - B_{t-1}^{G*} + CA_t$$

The closure of the foreign sector is treated in various ways in different models. One may either set the current account exogenously and let the world relative price, e_t, move to align exports and imports with it, or set e_t and let the *CA* balance be endogenous. IGEM adopts the former method; that is, the price of imports and exports move with the endogenous e_t so that equation (60) is satisfied.

B1.7. Market balances

In IGEM with constant returns to scale and factor mobility, equilibrium prices clear all markets at zero profits each period.

In the commodity markets, the demands in the economy consist of intermediate demands by producers, household consumption, investor demand, government demand and exports. The supply is given by equation (54). In equilibrium we have, for each *i*,:

$$(62) \qquad P_i^X XS_i = \sum P_i^X X_{ij} + P_i^X (C_i + I_i + G_i) + P_{C,i} X_i^x$$

In the capital market, the demand for capital input from all industries and households equals the supply:

$$(63) \qquad P_t^K KS_{t-1} = \sum_j P_{K,jt} K_{jt}$$

Since capital is mobile across sectors, there is only one price for capital rental that is needed to clear the market. However, in the data, widely different rates of return are observed. To reconcile this, the industry rental price is assumed to be a fixed multiple of the economy's endogenous rental price:

(64) $P_{K,jt} = \psi_j^K P_t^K$

Similarly, in the labor market, the assumption of mobile labor requires the industry specific labor price to be a constant times the economy's market clearing price:

(65) $P_t^L LS_t = \sum_j P_{L,jt} L_{jt}$; $P_{L,jt} = \psi_j^L P_t^L$

The government deficit (equation 52) is satisfied by endogenous spending on goods and services, V^{GG}, and the current account surplus (equation 60) is satisfied by endogenous changes in the world relative price, e_t. The final item is the saving and investment relation:

(66) $S_t^{hh} = P_t^I I_t^a + \Delta G_t + CA_t$

Household saving is first allocated to the two exogenous items – lending to the government to finance the public deficit and lending to the rest of the world. The remainder is allocated to investment in domestic capital. As explained in earlier, in IGEM there are no separate saving and investment decisions; equation (66) holds as a consequence of household intertemporal optimization[24].

IGEM is homogenous in prices. Doubling all prices leaves the equilibrium unchanged. Therefore, any price may be chosen for the purposes of normalization. In IGEM, the after-tax price of labor received by households as the selected as the numeraire and is exogenous to model simulations. In addition, any one of IGEM's equations is implied by Walras Law, that is, if *n-1* equations hold, the *n*th also will hold. In the current implementation of the model, the labor market equation (equation 65) is dropped and is checked at solution to see that it indeed holds.

B1.8. Data underlying the model

The important data issue relating to the production component of the IGEM model is to identify the price and quantity data that correspond to the concepts laid out in the official input-output tables and that are consistent with the demand components of the model.

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[24] In other models where investment is derived separately, e.g. due to sector specific reasons, an endogenous interest rate will clear this S=I equation.

The dollar values from the input-output tables are obviously the ones to use to characterize the nominal output of the industries ($P_{QT,jt}Q_{jt}$). IGEM's principal data source is the time series of IO tables put together by the Bureau of Labor Statistics (BLS), Office of Occupational Statistics and Employment Projections. These are constructed from the benchmark tables published every 5 years by the Bureau of Economic Analysis (BEA). This dataset gives the value of output and intermediate inputs of all sectors for 1983-2000. These are combined with an earlier BLS series for 1977-96, and an even earlier version of an internal IO dataset (Jorgenson 1998), giving a sample period of 1958-2000. The BLS dataset also comes with industry prices for the entire 1958-2000 period that are based on their Producer Price Indices (PPI). These are used as $P_{QT,jt}$.

The details of the construction of industry output and K,L,E,M inputs are given in Jorgenson, Ho and Stiroh (2003). The industry capital stock and capital input are derived from the BEA's Capital Stock Study which includes information on investment by 60 asset categories. The industry labor input are derived from detailed demographic and wage data in the annual Current Population Survey and decennial Census.

The data for the final demand for commodities are also made consistent with the benchmark Input-Output tables in the BLS time series. The consumption data for the third stage is taken from the NIPA Personal Consumption Expenditures as described in Jorgenson and Slesnick (1987). This is related to the IO commodity classification using a bridge table like that given in *Benchmark Input-Output Accounts for the U.S. Economy 1992*, Table D[25]. The data for aggregate labor supply and full consumption is described in Jorgenson and Yun (2001) and are derived from population time series cross classified by gender, age and education. The BLS IO series also provide the investment, government exports and imports by the IO commodities. The investment data from the BEA Capital Stock Study may be reconciled with the IO classification via the official IO bridge table (op. cit. *Benchmark* Table E). The government purchases are derived from the annual NIPA government expenditures by broad categories (e.g. *Survey of Current Business* August 2002, p 61, Table 3.7). The export and import data are taken from the detailed

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[25] *Survey of Current Business*, November 1997, page 50.

Census trade data and reconciled with the official NIPA goods and services trade accounts (*Survey of Current Business* August 2002, p 68, Table 4.3)

B2. Projections of exogenous variables

IGEM simulates the future growth and structure of the U.S. economy over the intermediate term of 25 to 30 years, after which growth is gradually slowed so as to achieve a necessary model closure by means of a zero-growth steady state. The time path of model outcomes is conditional on projections of key exogenous variables that ultimately stabilize to yield the steady state results. Among the most important of these variables are the total population, the time endowment of the working-aged population, the overall government deficit, the current account deficit, labor and capital quality, world prices and government tax policies. Many of these are developed from published sources, "official" and otherwise. The remaining variables are projected from the historical data that underlie the model and its estimation.

The key variable is population growth and demographic change. Population projections are taken from the U.S. Bureau of the Census by sex and individual year of age.[26] During the sample period the population is allocated to educational attainment categories using data from the Current Population Survey in a way parallel to the calculations of labor input described in Jorgenson, Ho and Stiroh (2003). Each adult is given 14 hours a day of time endowment to be used for work and leisure. This quantity of hours for each sex-age-education category then is weighted by labor compensation rates and aggregated to form the national time endowment. The index used is the translog index and the methodology is described in Ho (1989, Appendix C).

Projections beyond the sample period use the Census Bureau forecasts by sex and age. It is assumed that the educational attainment of those aged 35 or younger will be the same as the last year of the sample period; that is, a person who becomes 22 years old in 2020 will have the same chance of having a BA degree as a person in 2000. Those aged

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[26] Data may be taken from the Bureau of the Census website, data pre1980 in http://eire.census.gov/popest/archives/pre1980/popclockest.txt, data for 1980-90 in *U.S. Population Estimates by Age, Sex, Race, and Hispanic Origin: 1980 to 1999*, and data 1990+ in eire.census.gov/popest/data/national/tables/intercensal/intercensal.php. These population data are revised to match the latest censuses (e.g. 1981 data is revised to be consistent with the 1990 Census).

55 and over carry their education attainment with them as they age; that is, the educational distribution of 70 year olds in 2010 is the same as that of 60 year olds in 2000. Those between 35 and 55 have a complex adjustment that is a mixture of these two assumptions to allow a smooth improvement of educational attainment that is consistent with the observed profile in 2000.

The results of these calculations, shown in Figure B4, are that population is expected to grow at just under 1.0% per year through 2025, reaching in excess of 460 million by 2060. In addition, the slow improvement of educational attainment means that the time endowment grows only at a modestly faster rate of 1.1% through 2025 and matches population growth thereafter.

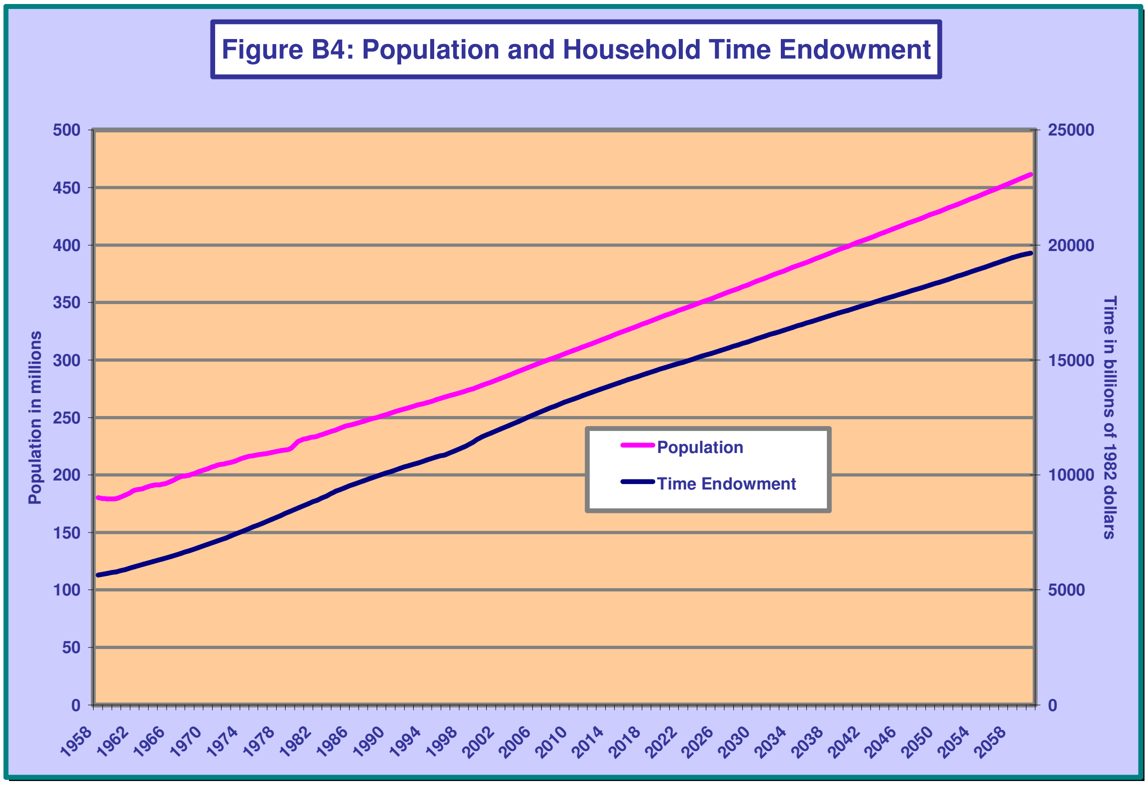


Figure B4: Population and Household Time Endowment

The total factor productivity (TFP) growth rate for each sector is projected using the Kalman filter in equation (11) above, curtailed to achieve steady state by 2050. To illustrate this procedure, Figure B5 plots results for selected industries while Figure B6 provides a historical perspective for the projections for all industries. A negative f_{pt}

reduces output prices below costs while a positive f_{pt} raises them above costs (see equation (4)). More importantly, a falling f_{pt} means that the relative price of output is falling more rapidly, i.e. there is positive TFP growth from a quantity perspective. As an example, in Electric Utilities, the sample period, 1958-2000, shows the f_{pt} term first falling, then rising and then falling again. Beyond 2000, IGEM's baseline projections portray, to varying degrees, steadily improving productivity in 30 of IGEM's 35 sectors. Leading the list in projected TFP growth is the well known IT producer, Electrical Machinery. There are, to be sure, several key sectors with negative projected productivity growth including the large Construction and Services industries.

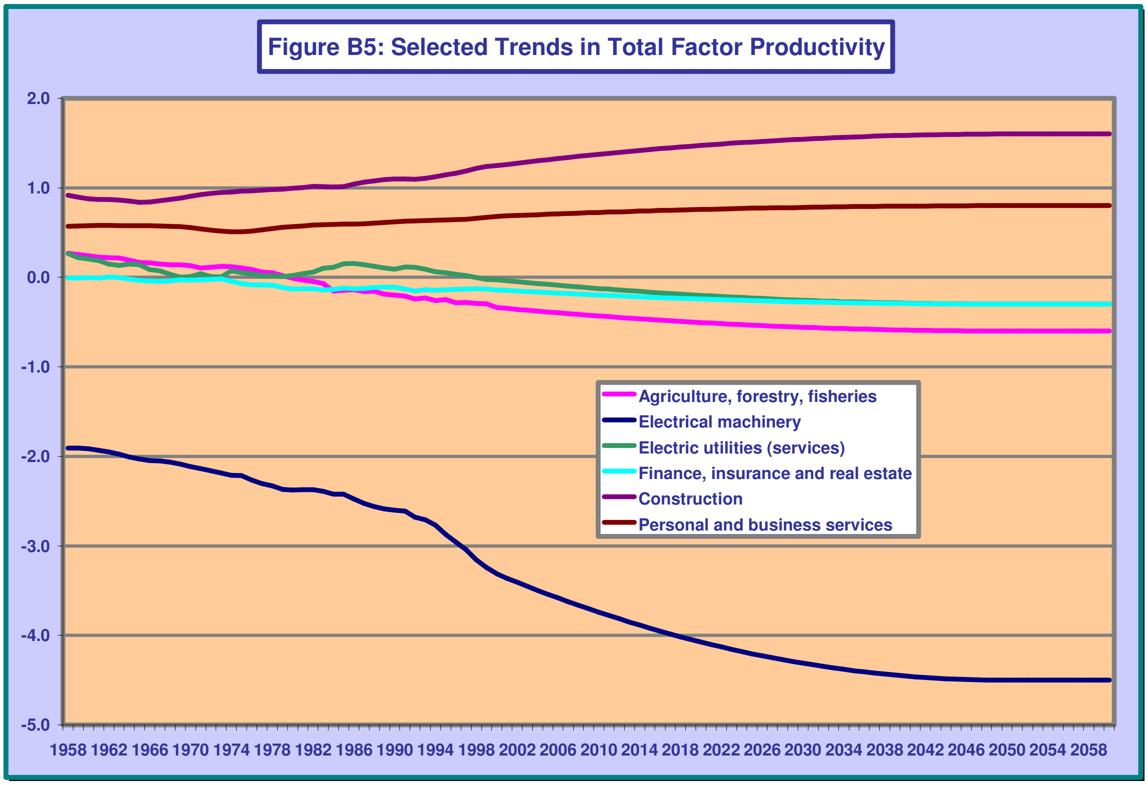


Figure B5: Selected Trends in Total Factor Productivity

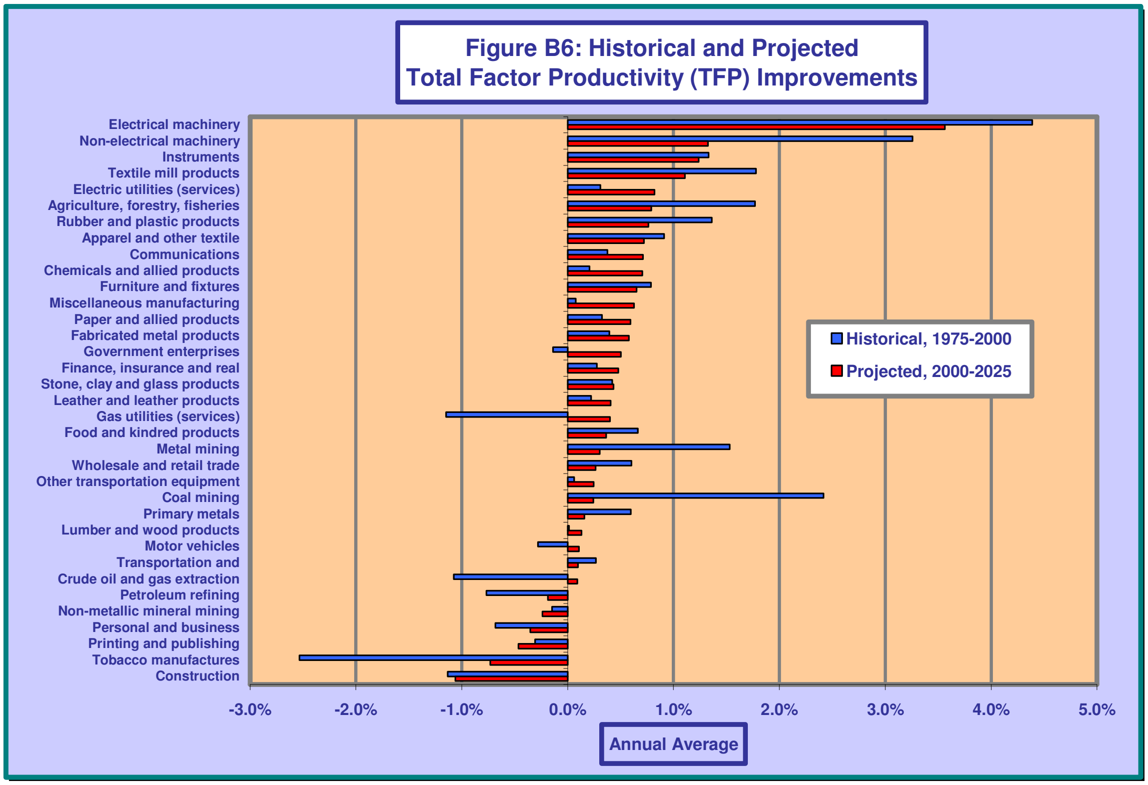


Figure B6: Historical and Projected Total Factor Productivity (TFP) Improvements

Projecting the factor biases of equations (4) and (6) is accomplished in a manner that is identical to projecting TFP. Figures B7 and B8 show the results for Electric Utilities and Electrical Machinery, respectively. Beyond 2000, Electric Utilities are projected to be energy-saving. Initially, they are projected to be capital- and labor-using and materials-saving but this reverses toward the end of the current decade. The high technology Electrical Machinery industry is projected to continue to be capital-using and labor-, energy- and materials-saving.

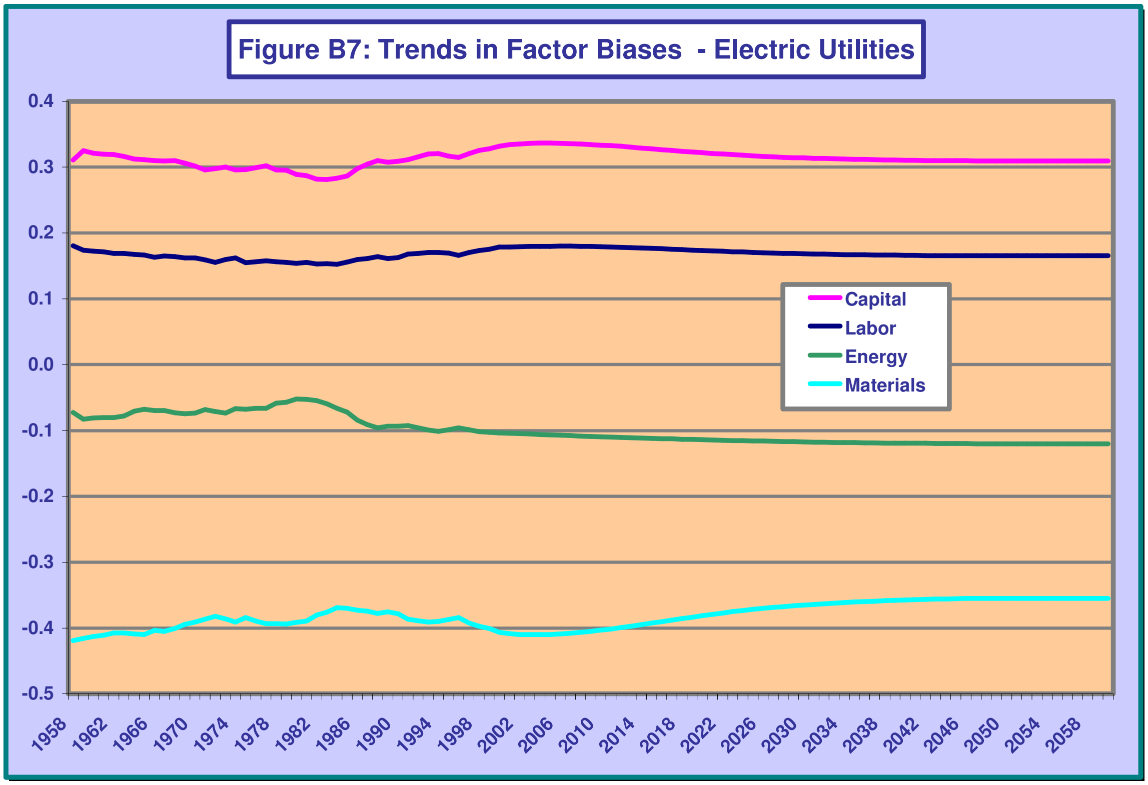


Figure B7: Trends in Factor Biases - Electric Utilities

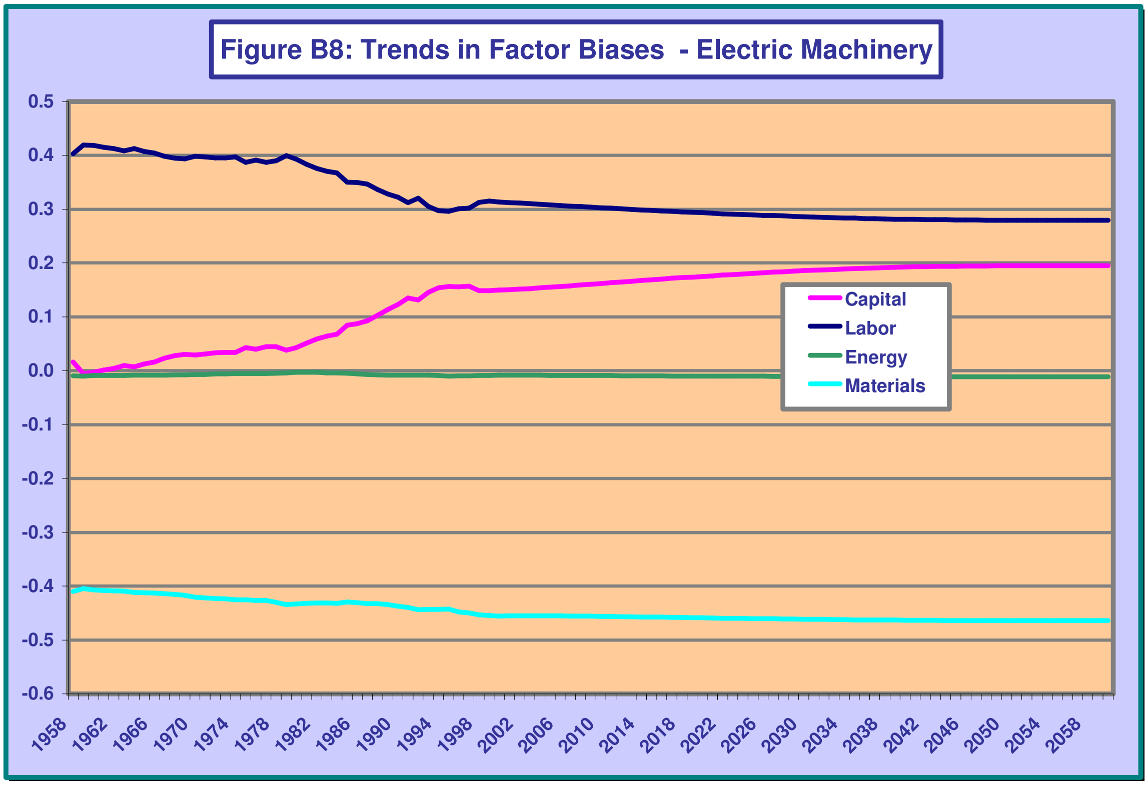


Figure B8: Trends in Factor Biases - Electric Machinery

Two other important assumptions that determine the shape of the economy are the government and trade deficits. To achieve a steady-state condition, the levels of government and rest-of-world indebtedness must stabilize to some invariant level in the future. This requires that the government budget and current account deficits trend ultimately to zero balances. The current base case assumptions are plotted in Figure B9. The government deficit follows the forecasts of the Congressional Budget Office (CBO 2003) for the next 10 years and then is set to track to a zero balance by 2038. The current account deficit is presumed to shrink steadily so that it reaches a zero balance by 2030. These simplifying assumptions allow the simulation a smooth transition path to steady state which permits easier computation along the way. These deficits are determinants of long run growth to the extent of their influence on base case capital formation but are substantially less important than the demographic and productivity drivers.

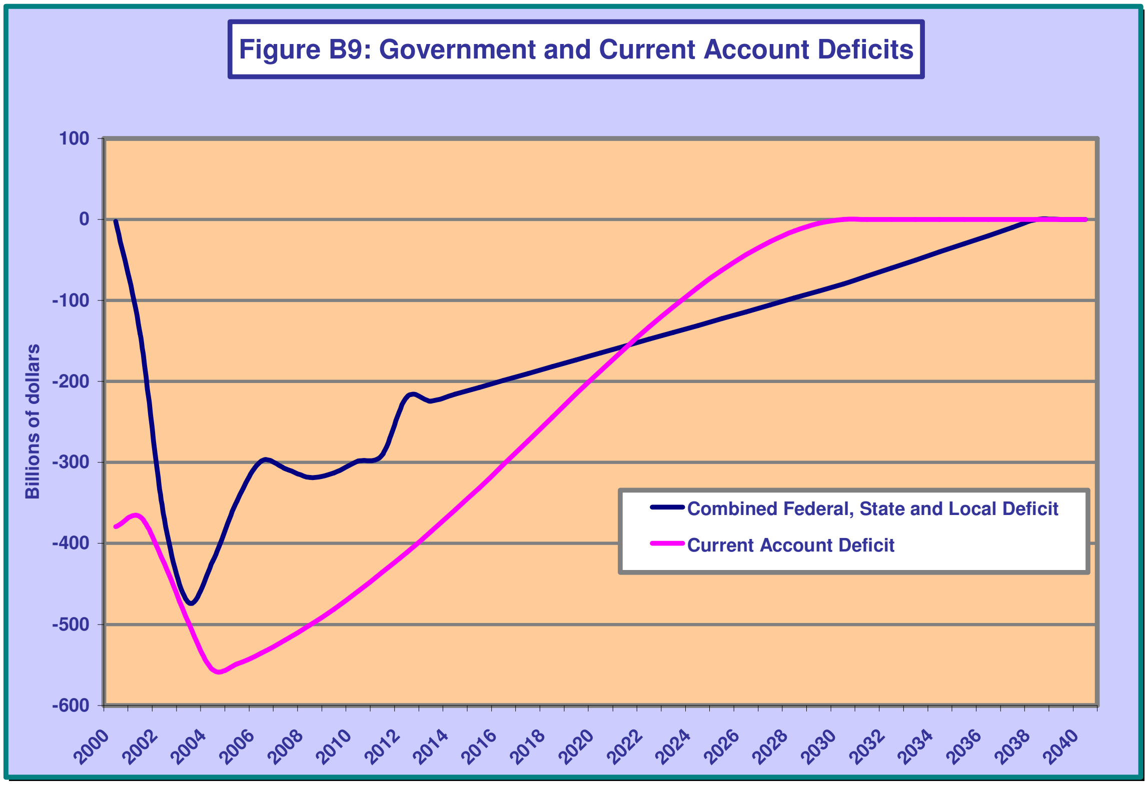


Figure B9: Government and Current Account Deficits

B3. The base case projection

IGEM's baseline path for the economy evolves through four phases. The near term, 2000-2010, represents a continuation of recent trends and conditions. The intermediate term, 2010-2025, reflects the onset of trends to eliminate the nation's budget and trade deficits. The long term, 2025-2060, involves a systematic transition of all input variables to their zero-growth, steady-state levels. Factor biases and autonomous productivity trends stabilize. Budget and trade deficits vanish. Tax rates and foreign commodity prices become invariant. Throughout each of these phases, there is a gradual slowing in the rates of population and labor force expansion and in the external forces governing productivity and factor substitution. In the case of the latter, there are still the interactions of these with IGEM's emerging patterns of relative prices and so the forces of price-induced technical change are still at work. Beyond 2060, the remaining two of IGEM's driving variables, population and the labor force, stabilize and the economy ceases to grow. This steady-state condition of zero growth is not a prediction; rather, it is an assumption of necessity for the model's solution.

The trends above are evident in the data on aggregate spending and inputs to production shown in Table B5. Growth in real GDP and personal consumption is initially in the 2.5 to 3.5% range but averages less than 1.0% over the interval from 2025 to 2060. Growth in capital input, arising from gross investment net of depreciation (capital consumption), and the availability of labor follow similar patterns of declining growth over time. Finally, aggregate productivity averages just under two percent, 2000-2010, just over one percent, 2010-2025, and 0.2%, 2025-2060. This last trend reflects the combined influences of the productivity projections described in the previous section.

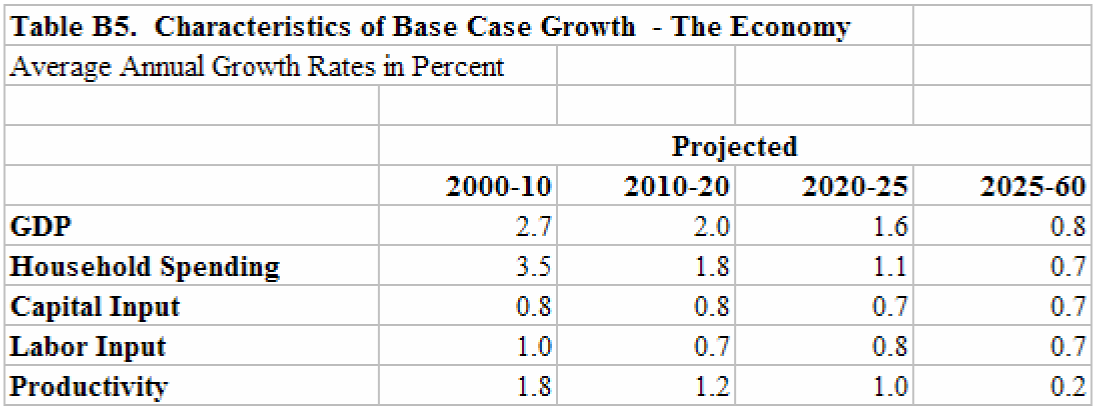


Table B5. Characteristics of Base Case Growth - The Economy				
Average Annual Growth Rates in Percent				
	Projected			
	2000-10	**2010-20**	**2020-25**	**2025-60**
GDP	2.7	2.0	1.6	0.8
Household Spending	3.5	1.8	1.1	0.7
Capital Input	0.8	0.8	0.7	0.7
Labor Input	1.0	0.7	0.8	0.7
Productivity	1.8	1.2	1.0	0.2

Growth in the total output of the U.S. economy, including all intermediate goods and services as well as all final spending (GDP), averages around 2.0% over the period 2000-2025. The projected industry mix, portrayed in Figure B10, evolves as an extension of recent market behavior. High technology manufacturing and the financial sector continue to enjoy relatively more rapid growth while the mining, metals and agricultural sectors continue to grow less rapidly. Domestic motor vehicle manufacturing and construction are also among the relatively slower growing industries.

Of particular relevance to this analysis are the emerging patterns of energy use and greenhouse gas emissions. Figure B10 provides evidence of the changing mix of energy inputs. All of the energy sectors experience slower than average rates of growth over the period 2000-2025. Domestic oil and gas extraction and coal production are the slowest growing, natural gas and electric utility outputs are the fastest growing and growth in petroleum refinery output lies in between. As shown in Table B6, aggregate fossil fuel use tracks the overall economy but at a slower rate. The carbon emissions from fossil fuel use grow initially at an even slower rate reflecting the changing relative mix of energy inputs toward oil and gas and away from coal. Beyond 2010, this change in relative importance has largely occurred and the carbon emissions associated with fossil fuel use grow in line with the corresponding physical quantity.

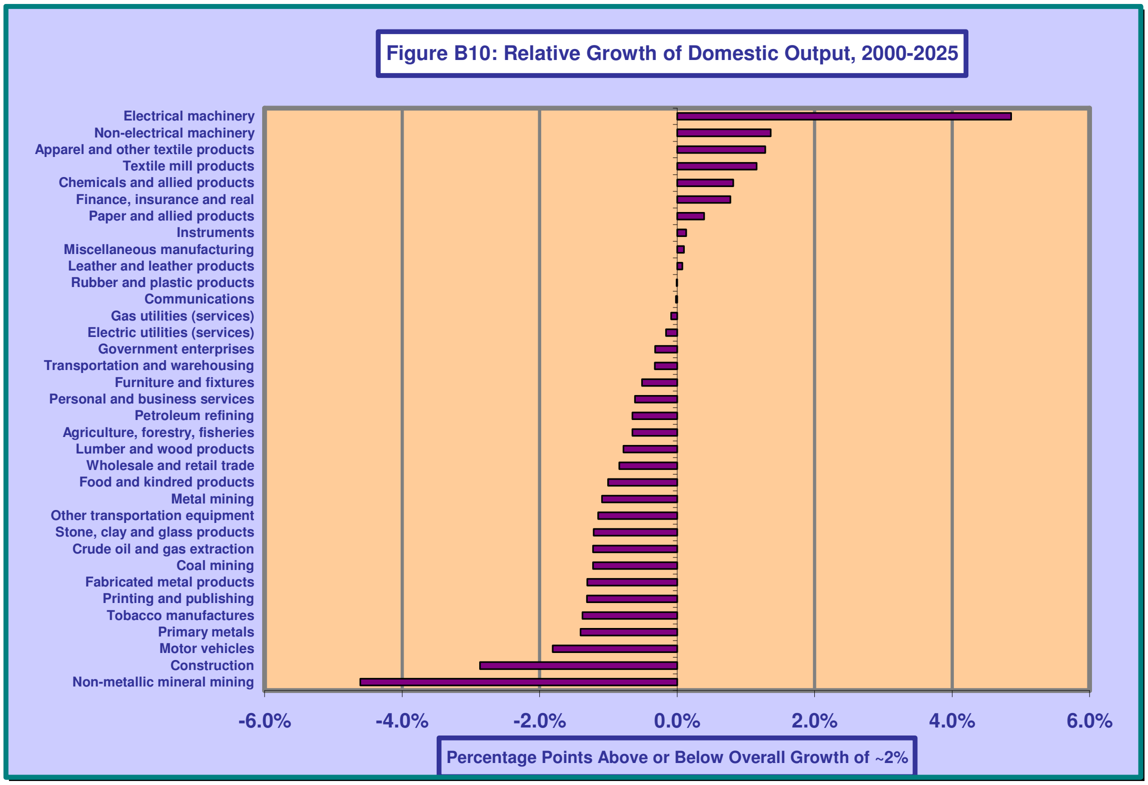


Figure B10: Relative Growth of Domestic Output, 2000-2025

Table B6. Characteristics of Base Case Growth - Energy and Emissions

Annual Average Growth Rates in Percent

	Historical			
	1990-2000	**2000-2010**	**2010-2025**	**2025-2060**
Fossil Fuel Use	1.6	1.7	1.1	0.6
GHG - Covered Activities	1.5	1.2	1.0	0.6
GHG - Total	1.4	1.2	1.0	0.5
Carbon from Fossil Fuel Us	1.7	1.5	1.1	0.6

As discussed in Appendix A, the (physical) energy and emissions coefficients for fossil fuels (coal, oil and gas) are constant over time while a common and declining trend is adopted for the emissions coefficients attached to all other economic activities (e.g., agriculture, chemicals, metal manufacturing, electricity transmission and distribution, etc.). Thus, in these latter cases, there are degrees of "autonomous" change reflected in the base case emissions projections. This is evidenced in the projections of greenhouse gases presented in Table B6. Greenhouse gas emissions, both covered and total, grow more slowly than fossil fuel use and the emissions from same because of the structural changes in the mix of economic activities and because of the representation of observed behavior in the form of “autonomous” efficiency improvements.

Projected energy- and emissions-efficiency improvements continue well into the future but at rates that are somewhat slower than historically observed (see Table B7). The annual reduction in the energy-intensity of real GDP averages 1.0%, 2000-2010, with emissions efficiency improvements averaging 1.2% for the carbon from fossil fuel use and 1.4 to 1.5% for total greenhouse gases. The annual rates of energy- and emissions-efficiency improvement diminish as the economy heads toward steady state, averaging 0.3%, 2025-2060. It should be noted that these diminishing rates of efficiency improvement also are consistent with the broader trends of recent history.

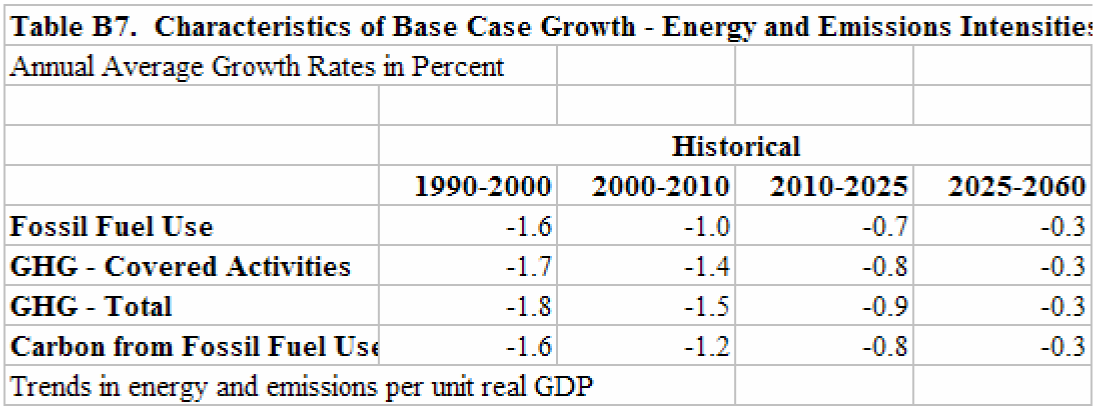


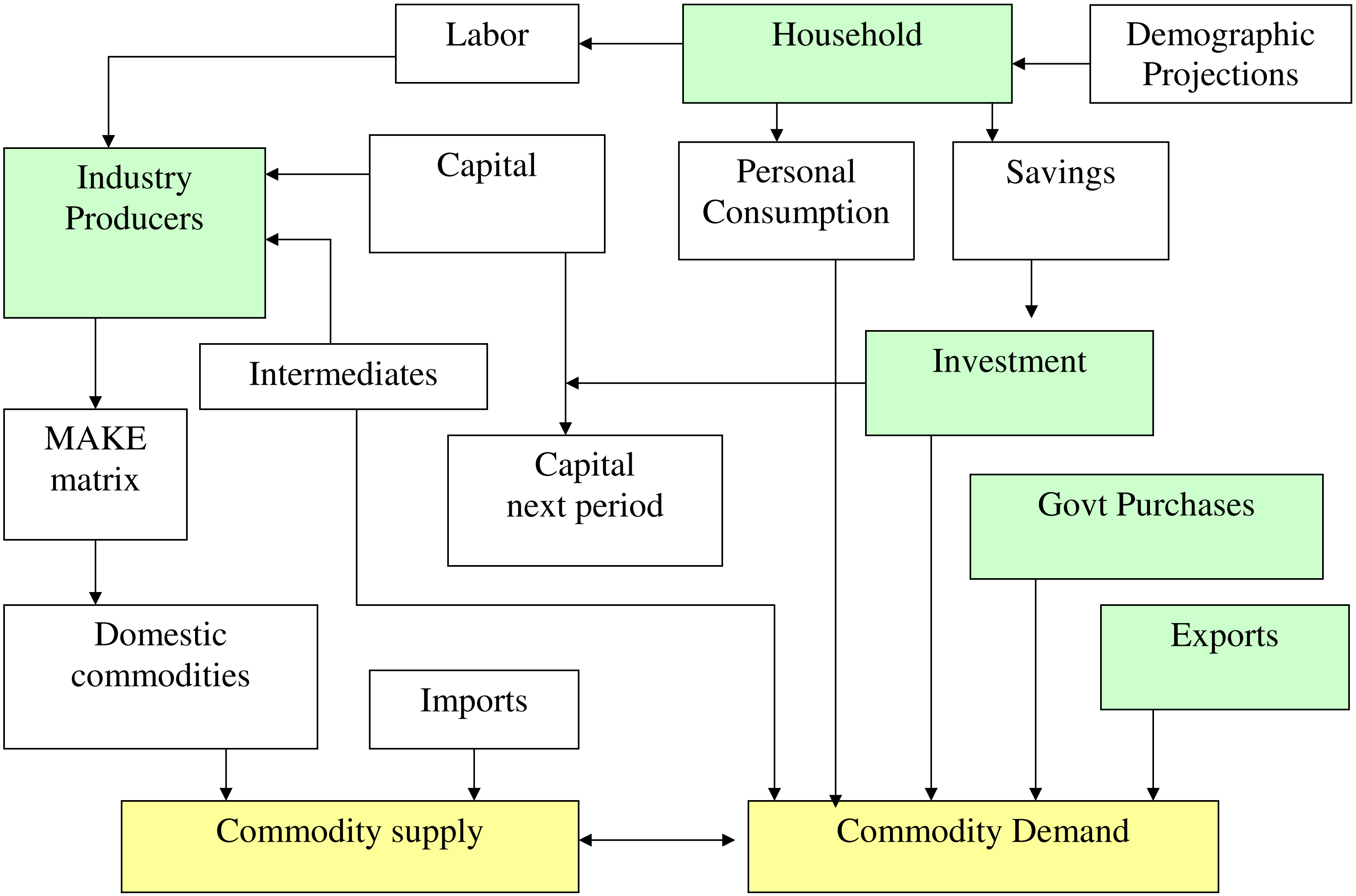
Table B7. Characteristics of Base Case Growth - Energy and Emissions Intensitie

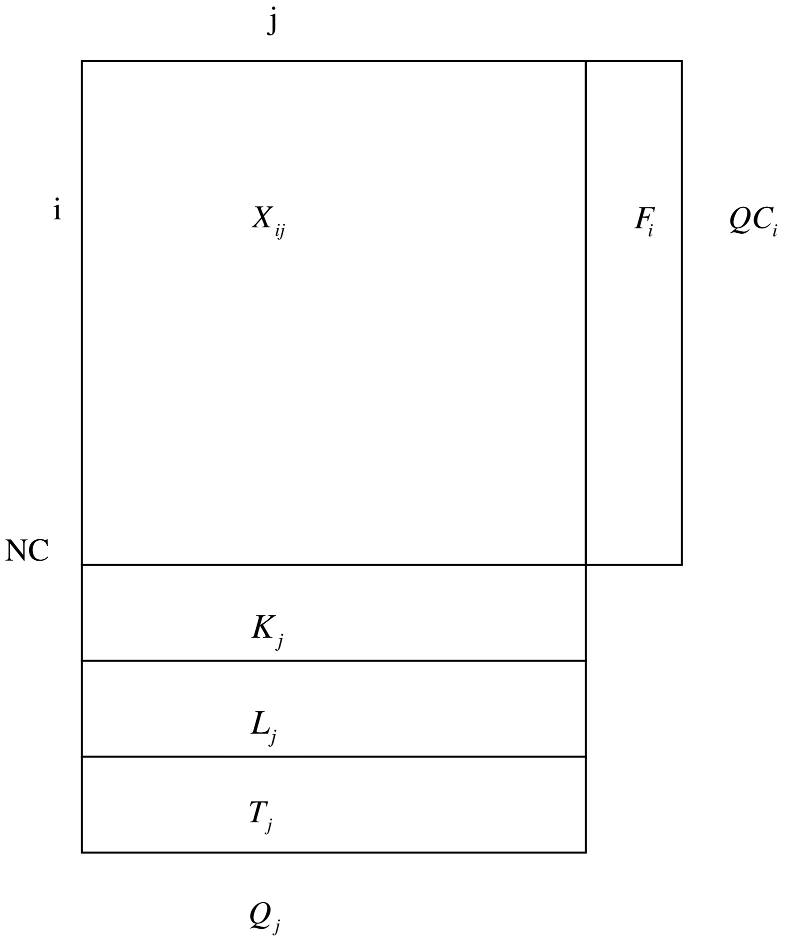
Annual Average Growth Rates in Percent

	Historical			
	1990-2000	**2000-2010**	**2010-2025**	**2025-2060**
Fossil Fuel Use	-1.6	-1.0	-0.7	-0.3
GHG - Covered Activities	-1.7	-1.4	-0.8	-0.3
GHG - Total	-1.8	-1.5	-0.9	-0.3
Carbon from Fossil Fuel Us	-1.6	-1.2	-0.8	-0.3

Trends in energy and emissions per unit real GDP

Figure B1: Flow of goods and factors in IGEM





Q_j: industry j output
QC_i: quantity of domestic commodity i
K: capital input
L: labor input
T: sales tax
NC: noncompeting imports
X_{ij}: quantity of intermediate input i into j
F_i: final demand for commodity i (C+I+G+X-M)
M_{ji}: quantity of commodity i made by industry j

Figure B2: Input-output USE table.

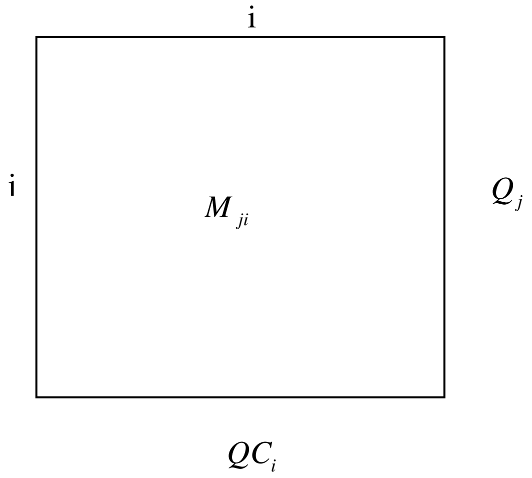


Figure B3: Input-output MAKE table.

Appendix C
IGEM's Saving-Investment Balance and the Government and Trade Deficits

Analyzing the impacts on government purchases, exports and imports requires discussion of IGEM's saving-investment balance. Each of the world's economies faces an identical accounting balance governing the pool of funds supporting private domestic investment and capital accumulation. The so-called saving-investment balance summarizes the net flow of funds available for investment. These funds arise from three sources. The first source is the domestic saving of households and businesses. All things being equal, increases in saving lead to more investment while decreases in saving lead to less.

The second source reflects the behavior of the collection of governments that comprise the national economy. To the extent that governments are running combined deficits, there occurs a crowding out of private investment as domestic saving is diverted to the accumulation of government debt. If governments are running combined surpluses, the opposite occurs. The reduction in government indebtedness augments private saving and releases additional funds in support of capital formation. Under conditions of balanced budgets, there is no incremental impact on investment from governments; private saving funds private investment while net tax receipts fund government spending.

The third source focuses on a nation's interactions with the rest of the world. A nation's private-sector claims on the rest of the world increase when it runs a trade surplus, becomes a creditor nation and, accordingly, invests overseas. All things being equal, private investment is diminished as a portion of domestic saving is diverted to investing (saving) abroad. However, when a nation runs a trade deficit, it becomes a debtor nation and saving and investment by foreigners augment domestic saving to increase the flow of funds to private investment or to government deficits. In this case, the pool of domestic funds is increased by the accumulation of foreign indebtedness. In the circumstance where there is no period-to-period change in net claims on or indebtedness to the rest of the world, there is no incremental impact on investment from the foreign sector; private saving funds private investment while inflows from abroad fund outflows overseas.

In the very long run, IGEM is required to achieve a steady state in both baseline and policy simulations; ultimately, there is no longer any growth in model inputs or outputs. Consistency with this steady state requires that there be no period-to-period changes in the levels of government and rest-of-world indebtedness. In turn, this means that the combined federal, state and local government deficit and the foreign current account balance each eventually converge to zero. It also necessitates that these and their corresponding levels of debt be external (exogenous) to a model run. More importantly, *in policy simulations*, the assumptions adopted for the baseline generally and intentionally go unaltered. By design, it is highly desirable in counterfactual and policy simulations to have the impacts on investment and capital formation arise solely from the impacts on domestic saving without influence in either direction from the actions of governments or from changes in the saving-investment behavior of the rest of the world. To accomplish this requires that simulations be deficit neutral in terms of their impacts on governments and current account neutral in terms of their impacts on foreign transactions; that is, year-by-year estimates of the government (federal, state and local) and current account deficits are identical across base case and policy simulations. This limits the impacts on investment to only those that originate from the saving and investment decisions of households and businesses.

To eliminate governments' direct effects on real investment spending, the simulations conducted for this analysis assume not only deficit but also revenue neutrality. As there will be no change in private investment arising from changes in government indebtedness, so too will there be no change in government spending arising from what otherwise would be lower tax receipts given a smaller economy. To this end, it is assumed that governments adjust taxes on household incomes in lump-sum fashion in order to preserve the annual levels of federal, state and local spending that occur in the base case. With both deficit and revenue neutrality in nominal terms, real government spending, therefore, must fall with rising prices or rise with falling prices so as to restore nominal expenditure to its "budgeted" amount. Given these conditions of neutrality, as the prices facing governments rise, there occurs a proportionally equal reduction in the real goods and services that governments are able to purchase. While there are numerous reactions concerning the fiscal policies of governments, each with their own implications for spending, deficits and, hence, investment, the above assumptions give rise to transparent outcomes that are uncomplicated by speculations on what governments might do to soften any adverse policy impacts.

The prices of U.S. exports rise relative to goods and services from the rest of the world. As exports are estimated to be price-elastic, export volumes fall by proportionally more than export prices rise. Because IGEM is a national model, there are no policy-induced income effects associated with exports; estimates of world income and real GDP enter only in base case construction and are policy invariant. With only the aforementioned price effects, U.S. export earnings decline.

Real and nominal imports also decline but the reasons are the net result of more complex interactions. First, import reductions occur from the overall reductions in spending associated with a smaller economy. Second, import reductions occur in those commodities directly affected by mitigation policy. The cap on emissions and the corresponding emissions permits fall on all of the commodities that contribute to U.S. greenhouse gases, irrespective of whether they were produced domestically or imported. Thus, within total imports, there are disproportionate reductions in oil, gas and other policy-sensitive commodities as their prices rise along with those of their domestic counterparts. Finally, there is the matter of import substitution which partially offsets the above two forces. Because IGEM is a national model, there is no mechanism, other than by speculative assumption, for adjusting the world prices the U.S. faces. Hence, for commodities not directly affected by policy, there is a greater incentive to import as U.S. prices now are relatively higher. For unaffected imports, there occurs a restructuring toward those commodities that obtain the greater price advantages in relation to those produced domestically and to those imports that are relatively cheaper within overall imports.

With only prices affecting exports and both prices and incomes affecting imports, the reduction in nominal imports exceeds the decline in export earnings. If left alone, the improved trade deficit would represent a capital outflow that would lower U.S. indebtedness to the rest of the world and, simultaneously, harm investment by augmenting the decline in domestic saving. To neutralize this impact so that the effects on investment arise solely from those on domestic saving, the dollar strengthens to the point where it restores the current account balance to its pre-policy level. The condition in policy experiments that the value of the dollar adjusts to preserve existing (i.e., base case) current account balances (i.e., desired foreign saving) and U.S. indebtedness (i.e., willingness to hold dollar-denominated assets) is intentional in that IGEM is specified to represent only the domestic U.S. economy.

The strengthening dollar has the effect of reducing exports somewhat more while reducing imports somewhat less. In real terms, import volumes decline slightly from base case levels, as import substitution and the strengthening dollar partially counteract the effects of a smaller economy and the reductions in emissions-intensive imports. In nominal terms, however, the decrease is more substantial as import restructuring and the stronger dollar also reduce the average landed price of imports. This complements the decline in import quantities yielding lower overseas payment obligations.

In the simulations in which there are no international permit purchases, current account balances and U.S. indebtedness to the rest of the world remain at their pre-policy levels. The adjustments in exports and imports, real and nominal, and in the value of the dollar are as just described. However, the situations in which the U.S. purchases emissions permits from other Annex I countries require additional consideration. Because IGEM is a national model with no mechanism for internally determining changes in foreign saving behavior, there is the natural question concerning the worst that can happen. Here, the worst case is an unwillingness by overseas investors to hold additional dollar-denominated assets. Operationally, the U.S. becomes a net buyer of foreign permits; this could be initiated as either a current or a capital account transaction. But, if export-import patterns and portfolio decisions respond in a way that leads to *reductions* in the trade deficit and U.S. indebtedness (i.e., international permits are sold to the U.S. but foreign investors simultaneously become less willing to maintain pre-policy asset levels), there occurs an additional capital outflow. This capital outflow combines with the aforementioned domestic saving effect to further restrict domestic investment. In the case with 15% offset limits, this amounts to only a few percentage points of the total investment effect. In the case with 50% limits, this outflow effect is proportionally higher. The U.S. is purchasing even more foreign permits and the additional offsets from foreign sources explain much more of the overall investment effect. The purpose in making an assumption that is admittedly less favorable to capital formation is to aid in establishing a plausible upper-bound estimate of the policy costs to the economy.