Economic Impacts of Reducing Greenhouse Gas Emissions

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Executive Summary

The UN climate change negotiations have shown that unless the United States commits to the reductions in greenhouse gas emissions needed in order to limit global warming, other nations will not do so. Without this international cooperation, all will face escalating damages and risks from climate change. Yet, some US interest groups nonetheless claim that the economic costs of reducing emissions would be unacceptably high.

Such claims are baseless. All economic studies of the issue conclude that even with currently available technologies, greenhouse gas emissions can be reduced 80 percent by 2050 without substantially affecting economic growth.

Moreover, the economic models used in these studies are based on pessimistic assumptions. They assume, contrary to much empirical evidence, that the economy is now operating at peak efficiency, so that all potentially cost-saving opportunities to save energy have already exhausted. They also ignore the likelihood that new and improved technologies for energy storage, biofuels and other renewable energy technologies will be developed in response to the opportunities and incentives that restrictions on fossil fuel use would open up. Most importantly, they ignore the economic damages that would be incurred if climate change continues unabated, and the benefits that would be realized from a transition to domestically available, non-polluting energy sources.

Even with these biases, economic studies of cost-effective policies to achieve this transition find that by 2030, national income and production would be only 1-2 percent below trend, and gross national product would almost have doubled.

In addition, the studies identify significant ways in which the costs can be minimized:

- Most importantly, an economy-wide cap-and-trade regime limiting carbon dioxide emissions would allow emission sources the market flexibility to decide how, when and where to reduce emissions for greatest efficiency.

- Strategic infrastructure investments and institutional changes to accelerate deployment of low-carbon technologies can help significantly.
- Taking advantage of low-cost mitigation and carbon sequestration opportunities through domestic and international offset programs can lower costs substantially.
- Auctioning permits to emitters instead of awarding them *gratis* will provide an important revenue source that can improve economic performance by restoring fiscal balance to the national budget, by funding strategic investments, or by replacing other taxes that are particularly onerous or distorting.

In addition, the United States has an opportunity to take the lead in rapidly growing clean energy industries that could take advantage of its technological capabilities and provide a wide array of well-paying jobs. If that opportunity is missed, other companies in Europe and Asia, which are already well down the learning curve in these industries, will capture global markets and the majority of jobs that are created.

Introduction

Reducing US greenhouse gas emissions by more than 80 percent by 2050, as current Congressional bills propose, will require a far-reaching transformation of the economy. Fossil fuels will have to be largely replaced by low-carbon energy sources, and the economy must become far more energy-efficient.

Failure to enact legislation to accomplish this transition will undermine efforts to build international cooperation to stabilize the global climate. Other nations will not make comparable efforts without committed action by the United States. International cooperation is essential: no nation or bloc of nations can achieve climate stabilization without cooperation from all major emitters.

If international efforts fall short, the United States and other countries will face escalating risks of a wide range of climate change damages, including more frequent extreme weather, disruption of water supplies, frequent fire, disease and pest outbreaks, crop losses, ocean acidification and sea level rise, among other effects. These changes may become irreversible.

Despite these risks, many question whether the US economy can withstand the transition from fossil to low-carbon fuels without unacceptable costs and economic disruption. This paper summarizes recent attempts to use economic analysis to assess those concerns.

Two Competing Representations of the Economy

Forecasting the economic consequences and impacts of this transition juxtaposes two very different representations of the economy:

In one, the economy evolves through technological innovation, the creation of new products, and behavioral adaptation to new technological opportunities and resource constraints. In search of the profits potentially available by exploiting new technologies and markets, entrepreneurs and investors set off cascades of innovation and growth. New firms and industries emerge and grow; others decline. At any moment, some firms and households are on the leading edge of technological change; others are lagging behind. Innovation, entrepreneurship and investment respond to the opportunities presented in ways that cannot now be fully foreseen. Already, some of America's best minds are engaged in efforts to develop better batteries, fuel cells, algal-based biofuels and other energy innovations, with uncertain results.

This evolutionary view of the economy[1] suggests that the transition to low-carbon fuels could set off a surge of economic innovation and growth comparable to energy transitions of our past economic history: the transition from rail and animal transport to petroleum-based motor transport, or the transition from steam power to electricity. This evolutionary view of economic history draws on Josef Schumpeter's famous description of the process of "creative destruction" in capitalist economies and empirical evidence of long cycles of growth and consolidation.

Although this representation better reflects the dynamism of the modern economy, in which technological change is rapid and possibly accelerating, it has not been used to analyze the economic implications of mitigating greenhouse gas emissions. Evolutionary economics does not lend itself to analyses that yield definite forecasts or predictions. The "open" characterization of the economy, recognizing that new conditions and capabilities emerge over time, inevitably injects uncertainty and indeterminacy into analyses. Will genetic engineering enable massive and cost-effective production of biofuels? One cannot foresee with any confidence, any more than Thomas Watson, the founder of IBM, could foresee all the applications of digital computing. Will better means of energy storage be developed that will permit much greater deployment of intermittent wind and solar energy resources? One cannot foresee any more clearly than Thomas Edison could foresee the development of the immense variety of electric appliances.

In the other representation of the economy, which characterizes all the economic models used to analyze the consequences of greenhouse mitigation, all future technologies, capabilities, resource availabilities and prices are assumed to be known in advance. Firms and households respond to these foreseen conditions by developing optimal strategies that maximize profits or welfare. The set of possibilities included in the analysis must be "closed" so that a maximizing strategy can be found. The set of technological and other possibilities available not only today but in future decades must be assumed to be known, both to the analyst creating the model but also to the economic agents – firms and households – represented in it. In some models, the set of technologies represented in the model is extensive, though still closed. In some models, pre-determined improvements in costs or productivity over time are programmed into the model, but these are nonetheless assumed from the outset. In these models, the economy quickly achieves equilibrium based on efficient deployment of resources under these constraints and proceeds along a trajectory that allows all firms and households the best outcomes, given the technological possibilities.

The advantage of this representation is that with sufficient further simplifications it can generate definite results.[2] The implications of various policy choices can be compared to each other and to a "business-as-usual" scenario assuming no deliberate policy effort to mitigate greenhouse gases. Models can be run repeatedly under different assumptions regarding policy design, technological and resource availabilities, and costs in order to explore the impact of variations in these important conditions. Nonetheless, all such analyses harbor the key assumption that everything is known today about the technological opportunities and conditions that will emerge over the coming three or four decades, a heroic assumption.

In assuming that all households and firms are in a welfare-maximizing, profit-maximizing equilibrium position from the outset, this representation also implies, contrary to widespread empirical evidence, that there are no opportunities to reduce greenhouse gas emissions while saving money doing so. Armed with perfect information and foresight, firms and households represented in the model are assumed to exploit all available cost-saving investments and purchases within the technology set. This is assumed to be the case both in the policy simulations and in the baseline, “business-as-usual” simulation. If, in these analyses, the damages from climate change are set aside and the focus is only on mitigation costs, the implication must be that *any* deviation from the “business-as-usual” scenario must raise costs and reduce welfare, since in the business-as-usual case the economy was assumed to be already operating as efficiently as possible.

In stark contrast, many empirical studies of mitigation possibilities by firms, households and public sector institutions have found that a substantial percentage of total US emissions, from 20 to 30 percent, can be eliminated at a savings in costs or a super-normal return on the required investment.[3] These savings can be found in buildings, appliances, industrial processes and equipment, energy conversion, and transportation.[4] Since such opportunities contradict the assumption of efficient decision-making, many economists are skeptical that they can actually exist, but attempts to understand their persistence have uncovered a variety of explanations: lack of information, organizational inertia, misaligned incentives, and institutional obstacles, among others.

Overcoming these obstacles presents a broad agenda of potential policy interventions that could reduce emissions at little or no cost or with actual savings. The potential savings are almost certainly understated because studies of so-called “win-win” opportunities have examined each one in isolation, not taking into account their cumulative effects. For example, improved insulation, better use of passive solar design and natural lighting and ventilation, and water-saving equipment, might all be cost-effective in isolation, but when deployed together they might also allow down-sizing of the building’s HVAC system, with an additional savings in capital investment. Should such efficiency gains be captured in many buildings on a large scale, further savings in avoided investments in the upstream supply and delivery of energy might be possible. None of these possibilities is reflected in models that assume complete energy efficiency as a baseline condition.

These two elements of the analytical models used to assess the costs of greenhouse gas mitigation are sufficient cause to view their findings with caution, especially with regard to outcomes over the long term. The analyses are best suited to explore the implications of alternative assumptions regarding technological availabilities, economic reactions and policy alternatives. Nonetheless, since economy-wide policies to reduce greenhouse gas emissions have not yet been enacted, there is little other than these models on which to base expectations regarding costs and impacts.

Key Findings

Many models have been constructed along these lines to analyze the economic costs and impacts of greenhouse gas mitigation. Although they share the same basic representation of the economy, they differ considerably in structure and assumptions, and project quite different costs for the same policies and mitigation trajectories. Efforts have been made to understand how such differences arise, both by examining the models in detail and by carrying out formal "meta-analyses" that associate differences in predictions with the differences in model assumptions.[5] These efforts have identified both the most crucial assumptions that lead to different results and the commonalities in the findings of various economic model analyses.

The most significant findings from these investigations include the following:

Even under worst-case assumptions built into models, as greenhouse gas emissions fall by 80 percent by 2050, economic impacts are mild, and economic growth will continue robustly despite higher delivered energy prices. Under worst-case assumptions gross domestic product and household consumption might be 1 to 3 percent lower by 2030 than in the baseline scenario because of higher energy prices. This implies a marginally slower rate of economic growth over two decades, from about 2.71 percent per year to 2.68 percent per year. This predicted difference in growth rates is much smaller than the error such models make in forecasting economic growth over these lengths of time.

The predicted impacts on household welfare are even smaller because households will partially compensate for the higher prices of purchased goods and services by producing more of them themselves. For example, there would be fewer trips out for entertainment and more evenings watching videos and making dinner at home.

Even aside from the averted damages from climate change,[6] other benefits would offset a significant fraction of these economic costs. These benefits, which are considered in only a few of the economic models, include reduced mortality, morbidity and health care costs from improved air quality, and reduced dependence on imported oil.

The availability of technological options significantly affects costs. If the expansion of nuclear power is limited, if carbon capture and storage from coal and gas-fired power plants proves infeasible or prohibitively expensive, or if the expansion of wind, solar and geothermal power is restricted by a lack of transmission facilities, then the costs of achieving the reduction in emissions will be much higher.

The analyses also find that policy choices are important: good policy choices can substantially reduce costs.

The most cost-effective way of implementing a large, long-term reduction in greenhouse gas emissions is to create an economy-wide price on carbon through a comprehensive cap-and-trade system. "What, where and when" flexibility lowers costs compared to command-and-control approaches. A comprehensive approach lowers costs by including all sources of emissions. If some sources are left uncontrolled, some low-cost mitigation options may be sacrificed, and there must be tighter controls on the remaining ones, leading to inefficiencies, higher abatement costs and higher energy prices.

Taking advantage of all potential mitigation and sequestration options, including those in forestry and agriculture, can significantly lower costs. Similarly, allowing US firms to take advantage of low-cost sequestration and mitigation options in other countries will also lower costs substantially.

Auctioning the bulk of permits and recycling revenues in a progressive way will lead to greater employment and lower consumption losses. Allocating permits *gratis* to emitters and others puts assets on their balance sheets but leaves their operating incentives unchanged, so will not affect their operating decisions.

The Range of Predictions from Leading Models and Analyses

The Energy Modeling Forum at Stanford University[7] has for many years performed a useful service by bringing together leading analysts investigating these issues and enabling them to understand why their models produce different results. Analysts run their models using the same scenarios regarding the future mitigation trajectories.

Almost all of the models included in these comparisons have been developed either by macro-economists at leading universities or by economists at the national research laboratories. Their projections have figured largely in the policy discussions and continue to do so. The following figures illustrate the range of predictions these models generate.

Figure 1.
Projected Baseline Emissions and Mitigation Trajectories

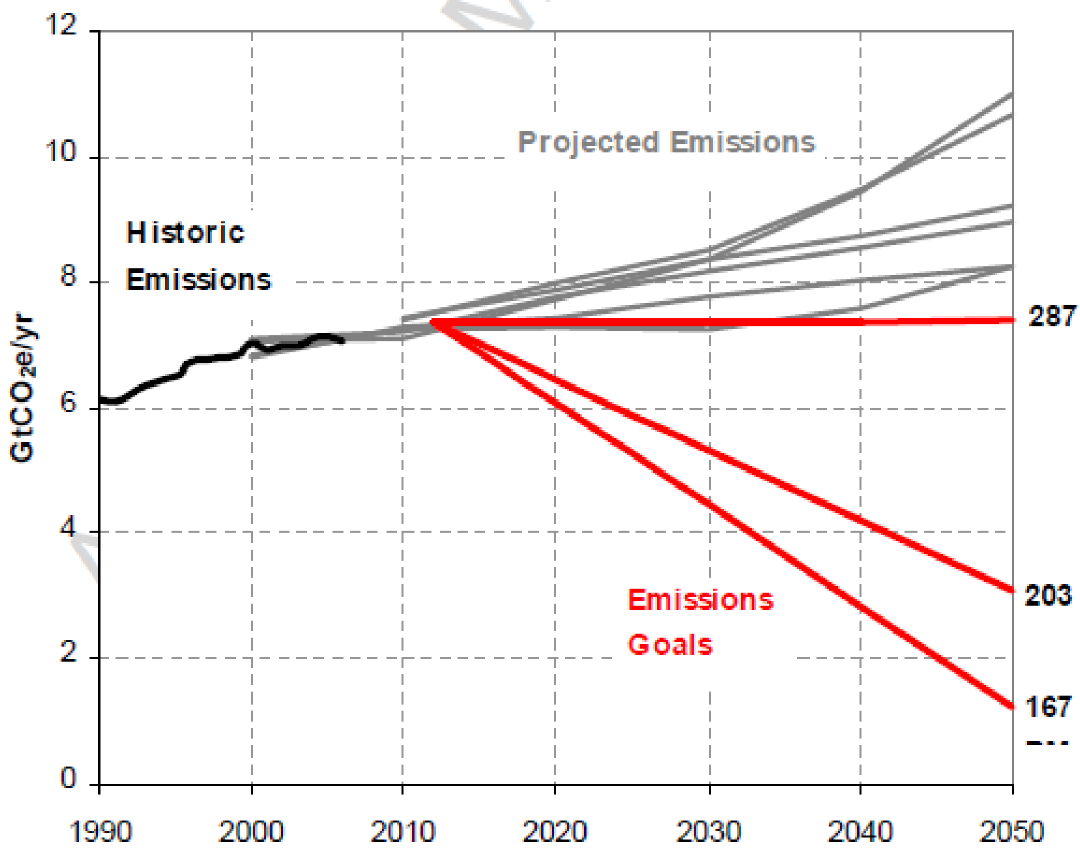
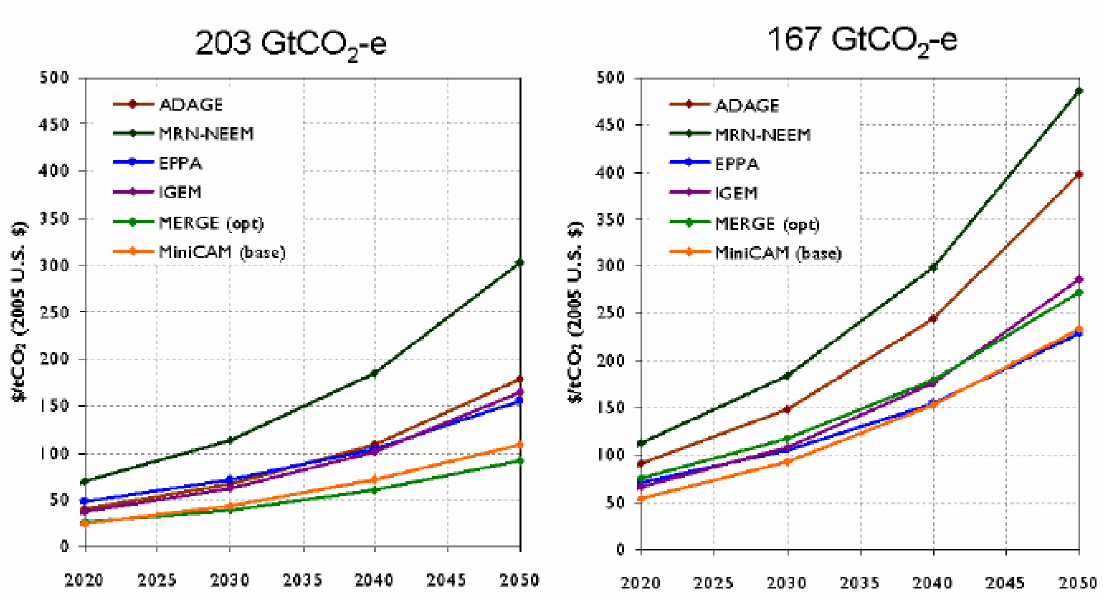


Figure 1 illustrates, in gray lines at the top, the projected business-as-usual emissions from 2000 to 2050 in six of these leading models. All projections are referenced to the latest available Annual Energy Outlook produced by the Department of Energy's Energy Information Agency, and take into account the most recent available energy legislation and economic forecasts. Nonetheless, it is obvious that different models predict widely different growth rates of emissions in future years under business-as-usual assumptions. In the most optimistic, emissions grow from about 7 to about 8 billion tons over 50 years; in the least optimistic, they increase to about 11 billion tons, a percentage increase more than three times as rapid.

The lines in red at the bottom of the figure represent the mitigation trajectories that all analysts used as a basis for comparing model results. The steepest decline represents approximately an 80 percent reduction from emissions in 2005, which is the trajectory proposed in current Congressional bills.

The higher the emissions are projected to be in the business-as-usual scenario, the more tons must be eliminated to achieve any mitigation target, and the higher the costs are likely to be. The differences in projected baseline emissions are attributable to differing assumptions about the pace of future labor force and economic growth, the ongoing improvements in energy efficiency and the shift away from carbon fuels in the absence of further policy stimuli. These assumptions play an important role in generating differences in predicted costs and economic impacts.

Figure 2
Projected Carbon Emission Permit Prices in Leading Models



The lines in Figure 2 are generated by 6 leading models, which have the corresponding acronyms included in the upper left of each figure. All analysts assumed that the mitigation trajectories would be achieved by an economy-wide cap-and-trade regime that requires all covered emission sources to hold a permit for any and all emissions during the year. The number of permits available each year would decline in step with the mitigation target. Permits would be tradable freely among sources, leading to one economy-wide permit price, which represents the minimal cost to fulfill the final ton of each year's mitigation obligation. Alternatively, given the models' assumptions of perfect competition and complete information and foresight, the lines could also represent the economy-wide tax on carbon emissions that would be needed to achieve the same emissions mitigation trajectories.

Although some economists have argued that the most effective policy response to the climate problem would be to put a price on carbon emissions by levying a carbon tax, Figure 2 illustrates why this approach would be unworkable in practice. First, what would be needed would not be a carbon tax, but a sequence of carbon taxes that increase year by year. It is unrealistic to think that a carbon tax, which would be expected to generate $50 to $100 billion in tax revenue each year, could be subject to such frequent rate changes. Second, there is considerable uncertainty about the rate that would be needed to accomplish any given mitigation trajectory. In the projections produced by various analyses, there is a three or four-fold difference in the carbon price consistent with a given mitigation target: in

2030, the required tax rate might be as low as $30 per ton or as high as $120 for the easier mitigation target. Even those favoring a carbon tax would be hard pressed to choose the appropriate rate.[8]

Technology Options

Why is the range of uncertainty so large, even in models in which everything is assumed known at the outset? In addition to the differences illustrated in Figure 1 in the number of tons that would have to be abated, the assumptions in the models regarding technology availability play an important role. If availability is unrestricted and the best estimates of future costs are assumed for various energy technologies, most models would forecast that the role of nuclear power would expand substantially as a source of low-cost baseload electricity, and future coal plants coming on line after 2025 would be equipped to capture carbon dioxide pre- or post-combustion and sequester it underground. If assumptions are built into models that limit the availability of these options or significantly raise their estimated future costs, then the predicted permit prices and overall costs of meeting mitigation targets would be higher. More reliance would have to shift to reductions in energy demand and to the remaining low-carbon energy sources.

Other assumptions about technology availability are buried deeply within model structures and require a close examination of model documentation to be understood. For example, some models assume very limited substitutability between fossil fuel power plants and wind or solar generation, such that the latter two's share cannot rise further than 20 percent of power generation, no matter how high the price on carbon emissions might go. Understandably, this restriction implies much higher carbon prices, especially if combined with limitations on nuclear power and carbon sequestration. The justification for this assumption is that intermittent wind and solar power can play only a minor role in the generation portfolio because there must always be enough dispatchable power sources to ensure reliable fulfillment of demand at all times. Underlying this restriction are pessimistic assumptions regarding future energy storage technologies and the transmission linkage of load and generating centers to smooth out fluctuations.[9] In addition, new large natural gas deposits recoverable from shale formations may encourage solar thermal and gas turbines to be paired in order to ensure economic and reliable low-carbon electricity generation. Such plants are already under construction.

In some models, assumptions are built in that imply rising cost curves as the installed capacity of wind and solar power expands. These assumptions are not based on historical data, which show declining costs for these renewable power technologies as installed capacity has increased. Models that project these declining costs into the future understandably imply lower overall mitigation costs and permit prices.

Important technological assumptions are also built into descriptions of energy-using sectors. The degree of substitutability between energy inputs to production and the use of capital and labor is one such significant assumption. In some models, production decisions are modeled as involving first a decision of the optimal mix of capital and labor, and after that a decision about how much energy to use with this mix. That's not generally the way it works. Most trade-offs regarding energy use come at the stage of plant design, when decisions are made whether or not to invest a bit more capital to install more energy-efficient equipment, lowering future operating costs. After that, managers decide how much labor to use to staff this plant: e.g., whether it should be operated for one daily shift, or two or three. Depending on the substitution elasticities chosen, such assumptions can significantly affect energy-saving responses to price signals. Importantly, these structures are simply assumed in most models, and parameters are not estimated from historical data but are chosen by the analyst.

Since the energy transition will take place over several decades, what the models assume about the drivers and pace of technological change is important. Typically, they assume a gradual improving trend in the energy efficiency of the economy, reflected in a trend of falling energy use per dollar of gross domestic product. Some models go further by extrapolating trends in the cost improvements of some energy conversion technologies. The faster are the assumed rates of technological improvement, the more favorable the economic impacts. Very few models go even further and embody assumptions that relate the rate of improvement in these technologies to the cumulative investment made in them. In many industries history reveals that as experience with a technology and investment in it increases, a series of incremental improvements leads to lower costs – a form of "learning-by-doing." The few models that encompass these learning curves of induced technological improvements find that economic impacts are more favorable because the economic incentives that promote a low-carbon technology lead to cost improvements over time in those same technologies.

Policy Choices

Models can be useful in assessing policy choices. Such analyses and actual past experience in environmental regulation have shown that market-based policies such as cap-and-trade regimes can keep costs down by providing firms and households flexibility about what greenhouse gases to abate, how to do so, where and when. The broader the coverage of such regimes, the greater will be the number and diversity of emission sources that will have incentives to reduce their release of greenhouse gases. One study found that exempting just three sectors responsible for 17% of emissions would raise permit prices by 30% and welfare costs by 30-50%.[10]

Partial and piecemeal policies are inefficient and raise costs. For example, vehicle fuel efficiency standards reduce emissions per mile but fail to encourage owners to drive fewer miles. Perversely, because operating costs are reduced, drivers tend to drive more miles, not fewer. Similarly, policies that shield electricity utility customers from rate increases that reflect the price of carbon blunt users' incentives to conserve electricity.

Nonetheless, "market fundamentalism" is unwarranted. Complementary institutional changes, information programs and enabling infrastructure investment will reinforce market incentives.[11] Using such measures, California managed to keep electricity use level for decades despite population and economic growth.

Cap-and-trade programs are typically designed to cover carbon dioxide emissions by electric utilities and large industrial facilities, as well as emissions from transportation and upstream oil and gas suppliers. In addition to these sources, there are mitigation possibilities applicable to other powerful greenhouse gases, such as methane, nitrous oxides and certain industrial gases. There are also carbon sequestration opportunities in soils and forests. Allowing users of fossil fuels to reduce their net emissions by contracting with sources of other non-carbon greenhouse gases, with those able to sequester carbon out of the atmosphere, or with emitting sources outside the United States to carry out abatement measures is one of the principal means to provide *what, where and how* flexibilities. These so-called "offset" programs have been embodied in the Kyoto Protocol and implemented through the Clean Development Mechanism, Joint Implementation and other mechanisms. If allowed, they will enable regulated sources of carbon emissions in the United States to reduce their net emissions more cheaply. Experience thus far has shown that there have been many low-cost abatement possibilities in sectors that would not be covered by a cap-and-trade regime. For example, industrial gases with a greenhouse warming impact thousands of times more potent than carbon dioxide have been brought under control cheaply in China and elsewhere.

Questions have been raised, based on past experience, whether such measures have really contributed to a global reduction in emissions or whether they have simply rewarded measures that would have been taken even without any further incentive, or whether they have simply displaced emissions from one location to another. Offset programs must be carefully designed and monitored to ensure that offsets are not approved unless their reductions are permanent, verifiable, and additional to those that would have occurred anyway. Nonetheless, analyses agree that if such offset programs are not allowed, significant low-cost options to reduce emissions or to enhance carbon sequestration will be passed over, and consequently the costs of achieving mitigation targets will be significantly higher.[12]

The flexibility to decide *when* to reduce emissions is provided by provisions in some policy proposals enabling emitters to bank permits for future use or to borrow permits to a limited extent from future years. This flexibility is especially useful for emission sources that are implementing mitigation programs that will take some years to complete, or for sources that expect lower-cost options to become available in the near future. Analyses have shown that allowing “when” flexibility through banking and borrowing permits can help reduce overall costs.

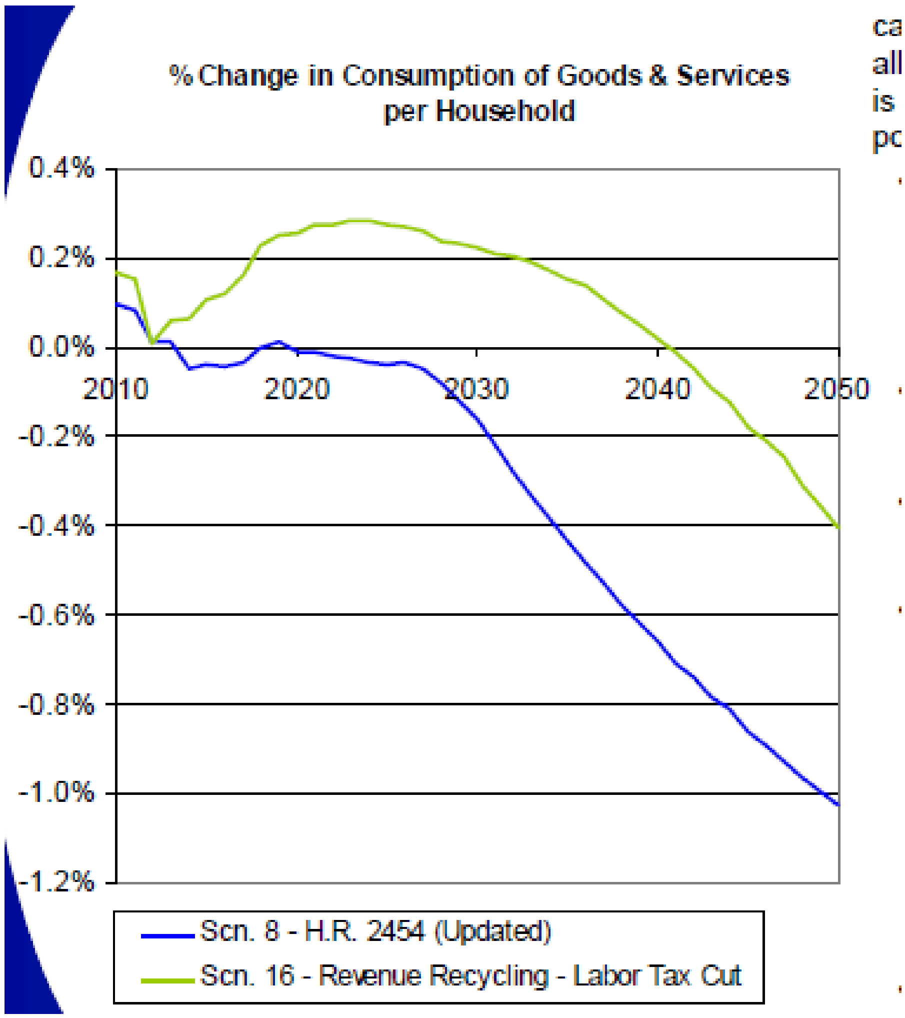
Another very important policy choice is the allocation of permits in any cap-and-trade program. The market value of permits in a national cap-and-trade program would be in the range of $50 - $150 billion in the program’s initial decades. These permit values would greatly exceed actual mitigation costs in the early years. Naturally, how these permits are to be allocated has become a burning political issue. Lobbyists representing various sectors and interests have besieged Congress, whose members have pushed forward the interests of their favored constituents. As a result, in proposed legislation, large fractions of permits are distributed free to these interests to “cushion” the economic impacts on influential constituencies, including electric utilities, heavy industry, agriculture, rural electricity users and others.

This policy decision is highly inefficient and inequitable. It transfers valuable assets (permits with a huge market value) onto the balance sheets of these firms, precluding other uses of the potential revenues. Moreover, because it is a lump-sum transfer of assets, it leaves the operating incentives of the recipients unchanged. Just as recent infusions of capital into the banking sector left their incentives to lend unchanged, since it did not change the balance of market risk and reward, the free allocation of permits to carbon emitters will not alter any propensity on their part to raise prices or reduce output.[13] Moreover, since it represents a new asset on the firms' balance sheets, the benefit will flow almost entirely to shareholders and creditors, not to employees or customers. This is a highly regressive disposition of the asset.

Studies have found repeatedly that auctioning permits and using the proceeds to improve the functioning of the economy would substantially lessen any adverse economic impacts of a cap-and-trade program. Typically, these analyses have examined the possibility of returning revenues to households and firms by lowering the marginal rates of taxes that distort markets.[14] These include taxes on payrolls and wage incomes, which discourage both labor supply and demand, or taxes on investment returns, which discourage both savings and investment. The higher the current rates of these taxes, the greater their distorting effects, and the more the benefit of using revenues from permit auctions to reduce them. Moreover, the equity implications of lowering taxes on payrolls and wage incomes are far more progressive.[15]

Figure 3 shows the results of an analysis using one model with a relatively detailed representation of the tax code.[16] It compares changes in household consumption over time if permits are allocated freely or distributed in a lump-sum fashion (blue), with changes expected if permits are auctioned and revenues are used to reduce taxes on wage incomes.

Figure 3

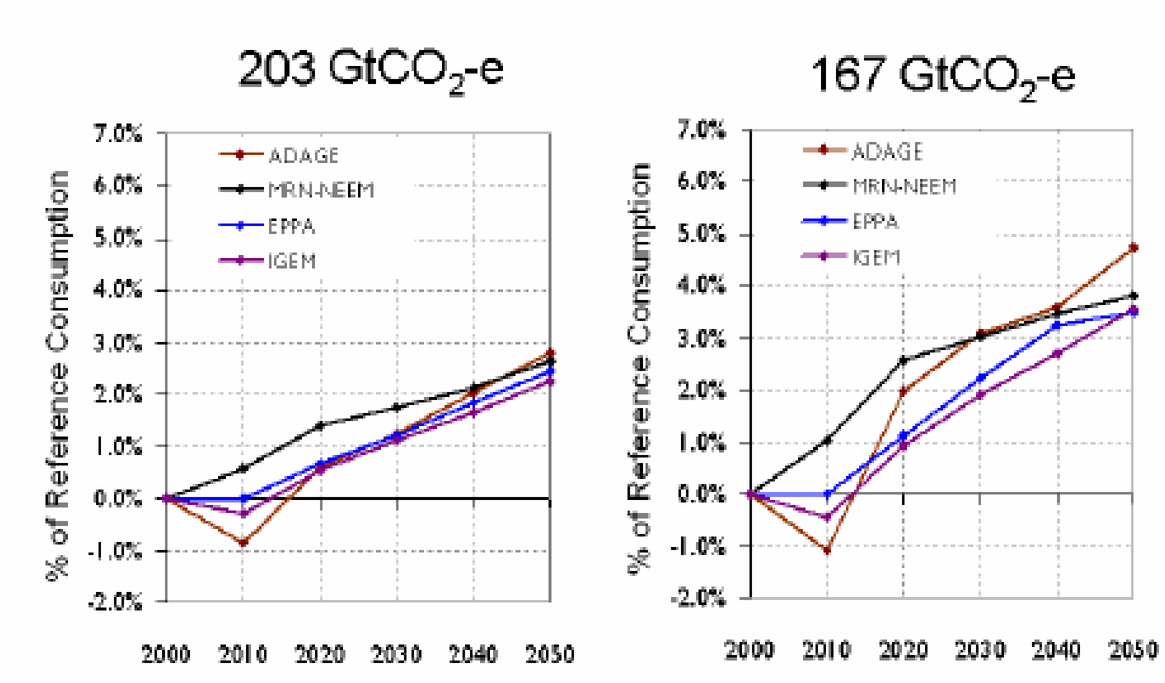


The differences are dramatic. The latter policy approach increases employment, household income and consumption over time relative to the results of currently proposed allocations that give most of the permits to favored interests.

Macroeconomic Impacts

In general, even with lump-sum distribution of any auction revenues, analyses all find that the macroeconomic impacts on gross domestic product, household income and consumption would be small. This is understandable. Energy expenditures have a small and declining share in total expenditures as the economy becomes a service-based economy, and the impact of carbon mitigation policies on delivered energy prices would be moderate. The energy charge in customers' electricity bills is a surprisingly small share of the total, and the increase in the average total bill would be less than 20 percent as the carbon cap phases in. The increase in gasoline prices at the pump would be much less than that experienced in recent years, when prices jumped to $4.00 per gallon. The US economy has many options with which to adjust to increased fossil fuel costs. Table 4 shows model comparisons of future aggregate household consumption relative to business-as-usual scenarios.

Table 4
Relative Reductions in Aggregate Consumption for
Two Mitigation Scenarios



There is close agreement among models that, relative to the baseline growth rate, the decline in household consumption under the (203GtCO2-e) mitigation scenario most closely resembling current legislative proposals would be between 1 and 2 percent in 2030, and between 2 and 3 percent by 2050. Therefore, household consumption would continue to grow almost as fast as in the reference case, a difference of only 0.1-0.2 percent per year in the growth rate. It would reach the reference case level after a lag of only one year – in 2031 rather than 2030. It is worth emphasizing that there is no support in serious economic analyses for contentions that enacting a comprehensive cap-and-trade regime designed to lower greenhouse gas emissions by 80 percent by the year 2050 would impose excessive or unsustainable costs on the economy or on households.[17]

It should be borne in mind that these projections of macroeconomic impacts are pessimistic, in that they don't take into account the damages that otherwise would be suffered on account of climate changes, or the savings that would be obtained from the transition to cleaner energy sources and reduced dependency on imported fuels. They are also pessimistic in basing projections solely on technological options currently available, with the exception of carbon capture and storage, ignoring any new technologies that may be developed for commercial use in the coming three or four decades. This may impart a significant pessimistic bias to the projections. On the other hand, the projections are also based on an assumption that policies that are adopted will be rational and reasonably cost-effective. Actual policies enacted by Congress may well fall short of this standard.

Impacts on Jobs and Competitiveness

Since the macroeconomic impacts on production and income are projected to be small, the macroeconomic effects on employment are also projected to be small.[18] A marginally slower rate of economic growth and rise in real incomes would tend to have a small adverse effect on the growth of employment. However, the increase in energy prices would offset part of that small effect by stimulating a shift from more capital- and energy-intensive industries and production methods toward more labor-intensive industries and production methods. Coal mining, oil and gas extraction and refining, and electricity generation have all become very capital-intensive. Energy-intensive industries such as iron and steel, cement and chemicals production are also relatively capital-intensive. Some industries that would expand in an energy transition, particularly energy efficiency services, construction, and solar power generation, are comparatively labor-intensive. On balance, the long-run economy-wide employment effects resulting from macroeconomic adjustments are expected to be marginal.

Some studies have predicted a significant increase in employment, but those estimates are predicated on a "stimulus package" of expenditures and incentives financed by increased government borrowing. Naturally, any such fiscal stimulus will lead to a short-term increase in employment. Had the stimulus package adopted by Congress been devoted entirely to "greening" the economy, it might have generated 3-4 million jobs. Unfortunately, however, in the stimulus package so far adopted, less than 10 percent of the total dollar amount was devoted to such energy efficiency and investment programs, compared to 38 percent in China, 58 percent in the European

Union and 80 percent in the Republic of Korea.[19] That was a missed opportunity.

In the longer term, those expenditures would have to be financed through higher taxes or result in higher interest rates, either of which would dampen the employment gains. Nonetheless, to the extent that such a package resulted in cost-saving energy efficiency improvements or in investments with a super-normal rate of return, the result would be higher incomes and a faster rate of economic growth, with positive overall employment effects. The United States is one of the few countries where no distinction is made in the national budget between borrowing for investment purposes, which should produce an economic return sufficient to finance the debt, and borrowing for current operations.

The implication is, however, that some industries would be adversely affected relative to the business-as-usual scenario, and others would benefit. Fossil fuel extraction and refining and energy-intensive industries would grow more slowly; renewable energy industries and a wide range of industries that contribute to better use of energy or that are the least energy-intensive would be encouraged. For industries such as coal mining, a good part of the slower rate of growth of output under an upstream cap-and-trade regime would be offset by higher prices.[20]

Since those energy-intensive industries are involved in international trade and competition, the effects of domestic climate policies on them depend in part on what actions trading partners also take. Should trading partners not adopt climate policies comparable to those implemented in the United States, there would be considerable “leakage” to other countries in the form of shifting trade and production patterns.[21] Of course, the reverse is also true should the United States not adopt carbon restrictions comparable to those in other countries.

The United States and other mature industrial economies have an unfortunate tendency to protect their mature “sunset” industries, those which are tending to shift toward emerging industrial countries, often at the expense of their “sunrise” industries, in which wealthy, technology-rich countries usually have comparative advantage. The reason, politically, is that sunset industries and their unionized workers have well-established ties to communities and politicians, but newly emerging industries do not. The share of newly industrializing countries in world steel and chemicals production has been increasing for decades, for example, for reasons independent of any climate policies or concerns. At the same time, the steel industry is typically found at the center of trade disputes and demands for trade protection.

The modern theory of international trade points up the dangers inherent in this backward-looking orientation. In industries characterized by falling costs and increasing returns to scale, countries that gain a head start in establishing domestic production may gain a lasting comparative advantage. Domestic production can lead to an accumulation of production skills, the growth of complementary supplying industries, economies of scale, and falling costs created by "learning-by-doing" and learning curve advantages. The cost reductions gained through this head start might lead to a long-lasting and self-reinforcing competitive advantage in world competition: lower costs lead to increased production for export, and increased production leads to further cost reductions and further competitive advantage.[22]

Sadly, this phenomenon is already evident in the nascent wind and solar energy industries. Even though much of the technology was originally developed in the United States, by now China, Denmark, Germany and others have taken over the lead in production and trade because they moved more quickly and forcefully to stimulate those industries. Unless the United States shifts its industrial policy away from supporting sunset industries and begins to provide strong stimuli to emerging sunrise industries, it may be shut out of world market in these fast-growing sectors. The impact on exports, industrial production and employment would be unfortunate. Many new, high-paying jobs would be sacrificed to other countries.

A comprehensive cap-and-trade regime would be the foundation for this stimulus. By creating an assured market space for low-carbon energy sources and by raising the costs and prices of competing fossil fuel industries, it would encourage investment in renewable energy industries.

Conclusion: How to Approach Climate Policy Decisions

The economic analyses that have been carried out on climate policy decisions lead to the strong conclusion that even under pessimistic assumptions about future technology options and adjustment possibilities within the U.S. economy, the impacts of policies designed to achieve an 80 percent reduction in emissions by 2050 would be small. Economic growth and living standards would continue to improve, and at almost the same rate, even ignoring the averted damages from climate change and other environmental benefits. Under more optimistic assumptions and taking these benefits into account, living standards would rise more rapidly if effective and economical climate policies are put in place.

There is a common-sense rationale for this important conclusion: The impact of a transition away from fossil fuels is bounded by the share of energy expenditures in the U.S. gross domestic product and the rise in energy costs resulting from a transition to low-carbon energy costs. The former is small, well under 10 percent, and falling over time. The latter is certainly less than 50 percent. Therefore, the upper bound of potential economic impacts is about 4-5% of gross domestic product, even if no adjustments or innovations took place over coming decades. But, as many studies have shown, many adjustments are possible, including some that would actually save money in the long run.

The potential damages if this transition is not made are unbounded. If global emissions continue to increase as projected in business-as-usual scenarios, atmospheric concentrations of carbon dioxide equivalents will reach 800-1000 ppm by the end of the century. By that time, positive feedbacks, such as melting permafrost, disappearing sea ice, large-scale forest fires, and altered marine chemistry might make climate change self-perpetuating and irreversible by any available policy options. Although it is impossible to foresee all the possible consequences of a shift in climate beyond any experienced in the course of human civilization, the risks are obviously enormous.

The proper framework in which to think about climate policy is a balance of risks and costs.[23] The costs are bounded and relatively small. The risks are unbounded and potentially catastrophic. The costs of an energy transition should be seen as an insurance premium, costing only 1 or 2 percent of income, against the enormous risks of global climate change. It is a form of social insurance, since individual households cannot by themselves obtain such insurance. When compared to other existing forms of social insurance, such as national security or health insurance, it is obviously affordable.[24]

As most citizens and a growing number of business and political leaders now recognize, the issue is not whether to enact policies to make this transition, but how to design the best policies for the purpose. The analyses underlying this paper show that there are better and worse policy decisions. Making better policy decisions can reduce economic costs and impacts by a great deal, by more than half. Enacting a comprehensive cap-and-trade regime with banking and borrowing of permits, carefully crafted “offset” provisions, and productivity-enhancing use of revenues from permit auctions is the foundation. Building on this foundation with strategic investments in research and infrastructure and with supportive institutional and policy changes will accelerate the transition and also help to reduce costs.

[1] There is now a Society of Evolutionary Economics and a Journal of Evolutionary Economics. For an excellent example of this approach, see W. Brian Arthur: *The Nature of Technology: What it is and How it Evolves*, The Free Press, 2009.

[2] Many of these simplifying assumptions are problematic. Many models assume a single "representative" household, which precludes analyzing how different policies affect the distribution of income across households, and consequently spending and employment patterns. In most models, the number of goods and services are severely reduced into a few sectoral aggregates, implying the assumption that various goods and services can be readily substituted for one another at constant prices.

[3] For example, see the study by the respected international consulting firm, McKinsey & Co., *U.S. Greenhouse Gas Emissions: How Much and at What Cost?*, New York, 2007.

[4] Studies of mitigation potential worldwide have fund a similar range of possibilities. See Ernest von Weizsacker et al., *Factor Five: Transforming the Global Economy through 80% Improvements in Resource Productivity*, Earthscan, London, 2009.

[5] See Robert Repetto and Duncan Austin, *The Cost of Climate Protection: A Guide for the Perplexed*, World Resources Institute, Washington D.C., 1997, and a later interactive online meta-analysis at www.climate.yale.edu/seeforyourself.

[6] Models strictly abstract from climate change damages by assuming that no production costs are ever affected by weather and that households are indifferent to all sorts of weather events.

[7] Their most recent analyses can be accessed at http://emf.stanford.edu/research/emf22.

[8] One proposal includes a limited carbon tax covering petroleum fuels, with the rate linked to a cap-and-trade program covering electric utilities and major industrial sources. Such a rate would tend to fluctuate with movements in the permit price.

[9] Thermal solar plants are being designed with an associated gas turbine or with heat storage in salt solutions. Many technologists foresee a future fleet of plug-in electric hybrid vehicles with batteries that can be used when parked for electricity storage via smart grid connections.

[10] Sergey Peltsov, J.M. Reilly, H. Jacoby, J. Morris, (2009),"The Cost of Climate Policy in the United States:, *Energy Economics*, 31: S235-243.

[11] A key infrastructure investment is in interstate transmission lines to carry wind power from the interior to load centers. Decentralized decision-making over siting and financing impede progress. A key institutional change is "decoupling" electric utility revenues from generating volumes, thus providing utilities incentives to promote end-use energy efficiency.

[12] The first-best policy approach would be to bring emissions from these other sources under caps as well, to allow reductions in emissions to be traded on carbon markets.

[13] Only the cap on emissions and the resulting carbon price affects firms' incentives, which are the same whether or not the firms must pay for their permits.

[14] In the current economic situation, an alternative case can be made for using revenues from permit auctions to reduce the federal deficit. Doing so would also improve the functioning of the economy. Failure to reduce the deficit as the economy recovers would probably result in higher future inflationary expectations and interest rates, and would require significant future tax increases and expenditure cuts. Revenues from permit auctions devoted to deficit reduction would accomplish a significant reduction over a decade.

[15] It has also been proposed that permits be auctioned and the revenues be returned to all households equally in a lump-sum fashion. This is also more progressive in its implications than a policy that gives permits to companies, but does not improve the functioning of the economy because it leaves everybody's incentives unchanged.

[16] Most models represent federal taxes in a highly simplified way, assuming away the myriad exemptions, deductions and special provisions that distort the tax code and encourage inefficient tax avoiding behavior. These models understate the potential benefits of reducing the most distorting tax rates.

[17] Analyses that make more favorable assumptions regarding auction revenue recycling or that take into account co-benefits from reduced air pollution and other environmental damages related to fossil fuel use predict that economic growth and consumer welfare would be higher, not lower, if such a cap-and-trade regime were implemented.

[18] The models have a limited ability to deal with employment issues because they rule out any unemployment by assumption. They assume that all markets are in equilibrium, including the labor market, implying that wage adjustments always balance labor demand and supply.
[19] N. Robins, R. Clover & C. Singh, *A Climate for Recovery: The Color of Stimulus Goes Green*, HSBC Global Research, London, 2009
[20] An upstream cap-and-trade regime that requires permits to sell imported or domestic fossil fuels would operate like a government-enforced cartel for coal mining companies, restricting sales and pushing up prices. This is exactly what the OPEC cartel strives to do for petroleum producers, but without the assistance of government enforcement.
[21] In some legislative proposals, such leakage is combated by allocating permits to energy-intensive industries on the basis of their production levels, which creates incentives for those industries to maintain or increase production. Of course, such a policy undermines the intention of climate policy, which is to bring about a reduction in carbon emissions.
[22] Paul Krugman's contribution to this new understanding of international trade helped earn him the Nobel Prize in economics and is now incorporated into standard textbooks, such as Paul Krugman and Maurice Obstefeld, *International Economics: Theory and Policy*, Addison Wesley, 2004.
[23] This is the framework advanced by the influential Stern Review on the Economics of Climate Change, carried out for the British treasury. See Nicholas Stern, *The Economics of Climate Change: The Stern Review*, Cambridge University Press, 2007.
[24] Indeed, the military and intelligence agencies have come to understand climate change as a threat to national security, and the medical and public health professions see climate change as a health threat.