External Costs of Energy

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Glossary

British thermal unit (btu) The average amount of energy per degree Fahrenheit needed to raise the temperature of 1 pint of water from freezing to boiling at sea level, which is equal to the energy needed to raise the temperature by 1°F, from 60° to 61°.

common property It has exclusions on use and allocation of a benefit stream determined collectively by community agreement or through government.

e-folding time This is for exponential decay what doubling time is for exponential growth. Suppose that a stock can be described over time by exponential decay to zero. At initial time, the amount is X_0 and over time the amount is given by $X_t = X_0 \exp(-rt)$. The time derivative is given by $dX/dt = -rX_t$. At $t = 1/r$, $X_t = X_0/e$, where e is the exponential number, approximately 2.71828. The ratio $1/e$ equals approximately 37%, so the e-folding time is the time at which the stock declines by 63% of the original value X_0. For an annual decay rate, for example, if $r = 2\%$, the e-folding time is 50 years.

NO_x Oxides of nitrogen, such as nitrogen dioxide (NO_2) or nitrogen monoxide (NO).

private property This has exclusions on use and enjoyment of a stream of benefits that are determined by a private owner or owner's agent.

public goods or bads These are not depletable by use and not excludable.

Vickery auction named after Noble Laureate William Vickery, this refers to an auction designed to avoid strategic bidding and to encourage small incremental bids that reveal the marginal cost curves of the bidders. The total amount is specified in advance. Each bidder may submit multiple bids for incremental amounts, and the lowest bids are accepted up to the point at which the total amount is reached. All winning bidders are paid the same price, not the amount they bid, equal to the lowest of all the losing bids.

willingness to accept (WTA) A schedule of prices and quantities that gives the minimum amount a consumer would accept in exchange for giving up an additional unit, as a function of the number of units the consumer holds.

willingness to pay (WTP) A schedule of prices and quantities that gives the maximum amount a consumer would pay in exchange for obtaining an additional unit, as a function of the number of units the consumer holds.

The external costs of energy are the costs not reflected in the market price, well over 100% for some energy sources. This large divergence between the social cost of energy and the price occurs because of environmental externalities associated with conventional energy sources and national security subsidies for imported oil and for nuclear power. As we shift to imported energy supplies, the remaining investment in domestic energy supply—extraction, transportation, and transformation—is 8% of all investment in the U.S. economy (measured by fixed assets in 2001). Whether domestic or international, many of these energy investments (power plants, pipelines, refineries, and oil and coal extraction) last for 50 years or more. Market prices that omit externalities are encouraging consumption of fossil fuels, investments in military preparedness, international investments in fossil fuel supply, and domestic investments in low-fuel-economy vehicles. At the same time, the same market prices discourage investment in alternative energy technologies, discourage investment in high-fuel-economy vehicles and vehicles that use alternative fuels, and discourage investment in energy efficiency. External costs of energy provide incentives for long-term investments resulting in gross and lasting economic inefficiency.

External costs occur at each stage, from exploration to production, transportation, conversion, consumption, and waste disposal. National security external costs accrue to oil because of national defense expenditures to secure oil that are paid by general taxes rather than taxes on oil imports. National security risks from the use of nuclear power range from the risk of attacks on power plants to attacks on waste transport and storage and the spread of nuclear technology and material. External costs of fossil fuels result from pollution through environmental media—soil, oceans, freshwater, the troposphere, and the stratosphere. Damage occurs to human health, there is a reduction of ecosystem services to the economy, and there is loss of the intrinsic value of nature. Economic theory helps to focus on marginal (rather than total) external costs and to separate external costs from costs that have been internalized through the market or regulation. Economic theory faces formidable challenges due to joint pollutants, nondepletable catalytic pollutants, and nonconvex, subtle, cascading effects among physical, biological, and social systems. Overly narrow applications of economic theory, particularly marginal benefits and marginal costs of externality abatement, are harmful to the formulation of well-designed policy options. The limits of the economic theory of externalities justify policies, such as the Clean Air Act, that do not require a balancing of marginal benefits and cost to set ambient air quality standards. The challenge is to design, implement, and improve policies that address unintended, harmful effects of energy development, production, and consumption.

1. ECONOMIC THEORY OF EXTERNALITIES

Economic efficiency is defined as occurring when it is not possible to make someone better off without making others worse off, which occurs when the marginal social benefit of consumption equals the marginal social cost of production. In theory, with a specific definition of "perfect competition," markets achieve economic efficiency. Some of the assumptions are the absence of market power, markets that provide costless and accurate information, rational behavior narrowly defined, the absence of public goods (or public bads), and the absence of externalities. Externalities occur whenever decisions of economic agents cause incidental costs or benefits borne by others that are not reflected in market prices. In particular, external costs drive a wedge between social and private marginal benefits and costs (Fig. 1).

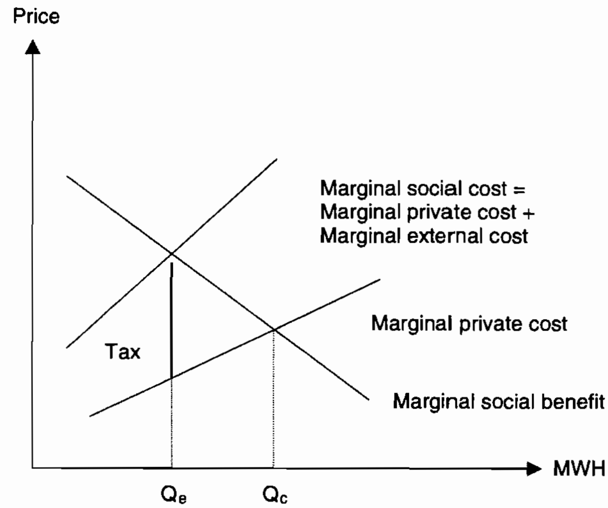

FIGURE 1 Marginal social benefit and cost.

If accurate information were costless, markets would be unnecessary. Markets provide imperfect information at a cost. All markets, whether for pollution credits, future prices of wholesale natural gas or electricity, or commodities sold to consumers, require government regulation to establish and enforce property rights. Property rights specify the right to pollute or, conversely, the right to a clean environment. Both markets and government enforcement of property rights that regulate markets are costly. Broadly, the idea of economic efficiency can inclusively consider the costs of markets and their regulation, including the costs of providing public goods and regulating externalities. In this sense, economic efficiency is the criterion most economists favor to evaluate policy changes. Although there is reason to be sympathetic toward the criterion of economic efficiency, the fundamental assumptions of economic efficiency are inconsistent with most applications to energy externalities. Finally, the criterion of economic efficiency is not adequate to assess strategies to reduce macroeconomic risks or technology forcing policies designed to alter the course of technological change.

1.1 Pigouvian Tax on Output versus Pollution Tax

The earliest analysis of externalities focused on external costs of production, for example, megawatt-hours (MWH) of electricity, where the marginal external costs are added to the marginal private costs to obtain the marginal social costs (Fig. 1). The amount consumed and produced by a competitive market equals Q_c, and the economically efficient amount is Q_e. In order to achieve economic efficiency, government imposes a tax on output equal to the external cost at Q_e. This approach erroneously assumes that the externality is produced in fixed proportions so that, for example, a tax to account for NO_x emissions from a natural gas-fired power plant would also be applied—in error—to a solar thermal power plant.

Modern environmental economics poses the externality problem in terms of the marginal benefit and cost of externality reduction (Fig. 2). The marginal cost of reducing NO_x is given by listing all methods of pollution abatement in ascending order of incremental cost. The marginal cost is negative until the curve crosses the abscissa at N_f because investments in electricity conservation per megawatt-hour are cheaper than the incremental cost of building and operating new power plants. N_f is the level of air pollution abatement that is actually a free lunch. The marginal benefit of externality abatement depends on the property right—whether the polluter has the right or the public trust establishes a right to a level of a clean environment. The marginal benefit is given either by the damaged party's willingness to pay (WTP) for abatement or the damaged party's willingness to accept (WTA) payment in exchange for enduring the damage (Fig. 2).

The WTA is greater than the WTP due to an income effect and a substitution effect. If the polluter holds the right, the damaged party's budget constraint limits the WTP, but if the right is held by the public there is no budget constraint on the WTA; this is the income effect. The substitution effect can be understood using the example of air pollution; there are no close substitutes for cleaner air, so the WTA is much larger than the WTP. If the correct marginal benefit curve is WTP, then the optimal amount of abatement equals N_P and the optimal pollution tax equals T_P. If the correct marginal benefit curve is WTA, then the optimal amount is larger, equal to N_A, and the tax equals T_A. There is no unique solution.

Both the WTA and the WTP curves emanate from the point N_c in Fig. 2. The maximum possible reduction in NO_x emissions is equal to the total emitted so that N_c corresponds to zero emissions to the environment. Consequently, whatever the property right, the social demand for externality abatement reaches the abscissa at the point of abatement where the negative externality is zero. In order to simplify the figures and discussion that follow, a single marginal benefit curve (MB) replaces the WTA and WTP curves.

1.2 Demand for Externality Abatement over Time

Demand for externality abatement shifts from MB_1 to MB_2 to MB_3 in Fig. 3 for two reasons—public goods and concentration of the externality. Public goods, such as increased national security or air pollution abatement, have one key property: They are nondepletable in consumption. The social demand for nondepletable goods is found by vertically adding individual demand, in contrast to

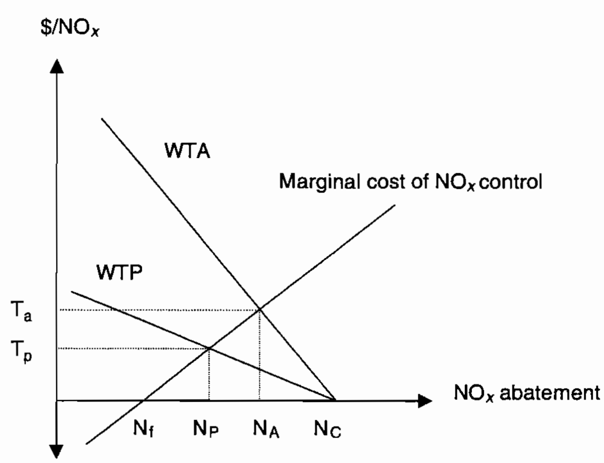

FIGURE 2 Marginal benefit and cost of externality reduction.

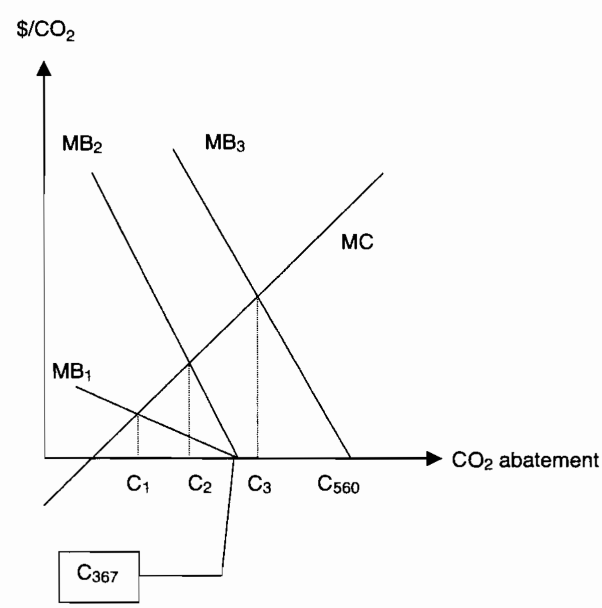

FIGURE 3 Optimal abatement over time.

the horizontal addition for private goods. Consequently, as population grows over time, the demand for externality abatement shifts from MB_1 to MB_2, holding pollution concentration constant.

An important air pollutant from fossil fuels is CO_2. CO_2 emissions have increased the ambient concentration of CO_2 since the industrial revolution. The ambient concentration was approximately 280 parts per million (ppm) in the late 1800s, and increased to 367 ppm by 1999. In the next 50 to 60 years, CO_2 concentration is forecast to reach 560 ppm, doubling the concentration since the preindustrial revolution. Within 200 to 400 years the concentration will increase 4 to 10 times unless we significantly abate emissions and sequester carbon from the atmosphere. In Fig. 3, let C_{367} represent the abatement necessary to return to 280 ppm in year 1999. Over time, the intersection of the demand for abatement and the abscissa will shift to the right, from C_{367} to C_{560} by the year 2055, resulting in the marginal benefit curve MB_3.

Over time, due to the public good nature of CO_2 abatement and population growth, and the growing concentration of the externality, the optimal externality abatement will increase from C_1 to C_2 to C_3.

1.3 Regulation, Internalization, and Incremental Change

Regulation internalizes the negative externality from pollution. For example, the local air pollution regulatory authority in the Los Angeles area established a set of stationary-source air pollution regulations requiring controls for power plants and oil refineries, among other pollution sources, to reduce particulates and precursors to ozone. The pollution control cost of electricity and refined petroleum products in southern California is reflected in the prices of these products. In 1990, the air basin was significantly out of compliance with the federal ambient air pollution standards—a point such as O_{1990} in Fig. 4. The federal standards for ozone, 0.12 ppm, exceed the state standards, 0.08 ppm, shown as $O_{0.12}$ and $O_{0.08}$, respectively. If the situation is correctly depicted in Fig. 4, the marginal benefit of abatement, B_{1990}, is greater than the marginal cost of abatement, C_{1990}, and additional abatement is efficient.

It is not possible, however, to estimate the marginal benefit curve for reasons discussed later. In the peer-reviewed literature, a team of economists, chemists, airshed modelers, and health experts estimated the incremental benefit to the Los Angeles region of attaining the federal standards for both ozone and particulate simultaneously. The estimate of incremental benefit equals approximately $10 billion for federal attainment and $12 billion (1990 $) for state attainment, so the incremental benefit of moving from the federal to state standards was $2 billion. If ozone and particulate were a single, homogeneous pollutant, and pollution abatement benefits were convex and met other technical assumptions in economic analysis, the incremental benefit of $2 billion could be shown as the area under the marginal benefit curve in Fig. 4. Unfortunately, the standard economic theory of externalities shown in Fig. 4 is incorrect.

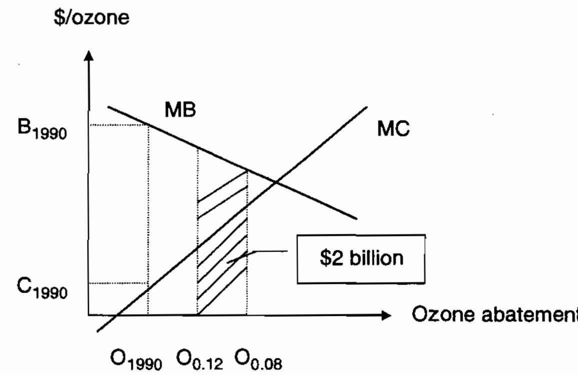

FIGURE 4 Partially internalized by regulation.

1.4 Joint Pollutants, Nonconvexities, and Nondepletable Catalytic Pollutants

Chemical reactions do not follow the assumptions of economic models. Ozone (smog) is created by the reaction of hydrocarbons and NO_x. Unburned hydrocarbons are released when we produce, process, and consume petroleum to get energy. Nitrogen, approximately 78% of the atmosphere, is stable at low temperatures, but fossil fuel consumption releases heat that creates NO_x. The ozone isopleths in Fig. 5A, similar to isoquants, give the combinations of reactive organic gases (ROGs) and NO_x that create a given amount of ozone. Because the isopleths include regions with positive slopes, in these regions decreases in NO_x actually increase the amount of ozone, holding ROGs constant, as shown by the arrow in Fig. 5A. The marginal benefit of NO_x abatement first rises and then falls, as shown in Fig. 5B, which is an example of nonconvexity.

Optimal abatement does not occur where the curves cross in Fig. 5B. First, if area A is less than B, it is better to do nothing (*ceteris paribus*). Second, emission control options typically reduce both NO_x and ROGs (*mutatis mutandis*), shifting the marginal

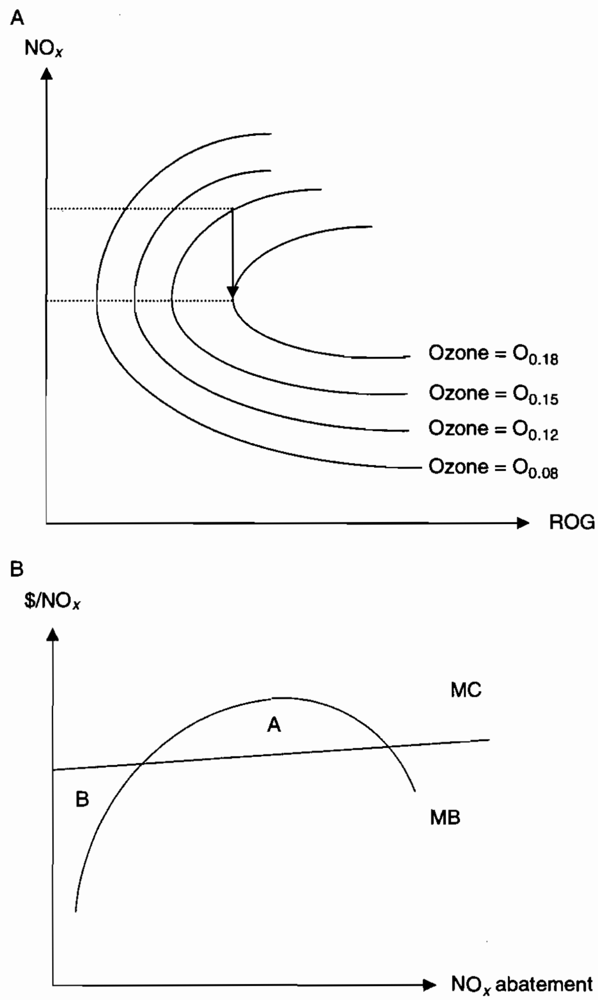

FIGURE 5 (A) Ozone isopleths. (B) Marginal benefit curve (MB) derived from isopleths.

benefit curve. Third, nitrate compounds from the nitrogen oxides are particulates with an aerodynamic diameter $< 10\,\mu m$, small enough to slip through the nasal barriers and lodge into the lungs. The human body's immune system reacts in ways that cause irritation and exacerbate respiratory disease. Consequently, NO_x causes damage directly as well as indirectly through ozone. Since NO_x acts as a catalyst in the formation of ozone, the same molecule can later contribute to particulate. The analogy in economic theory is a public "bad", which is nondepletable in use. Hence, the marginal benefit of abatement is found by adding the demand for particulate abatement vertically to the demand for NO_x abatement derived from the demand for ozone abatement. These complexities render obsolete the economic theory of externalities for application to energy from fossil fuel.

1.5 Nonconvex, Subtle, Cascading Effects among Physical, Biological, and Social Systems

Consider the policy of planting shade trees and painting surfaces white to lower the urban heat island effect, reducing the demand for air-conditioning to conserve electricity. Electric utilities change the dispatch order, altering the amount of electricity generated from power plants within and outside the urban airshed. The location of power plants and the emission control equipment determine the change in emissions of ROGs and nitrogen oxides, each of which separately causes damage to human health and the environment, that together form ozone in the presence of sunlight and an inversion layer. Surface roughness, affected by planting trees, alters mixing and transport within the airshed. Different types of trees have different emissions of ROGs, further adding to the complexity of impacts. Financial impacts include the dollar values of fuel, pollution credits, electric system reliability and associated timing of power plant investments, tree maintenance, and painting, in addition to the external costs of changes in emissions of greenhouse gases and carbon sequestration. This level of complexity further renders useless the modern economic analysis of externalities depicted in marginal benefit and marginal cost curves for abatement.

1.6 Measuring Policy Options: Partial vs General Equilibrium

The portrayal of economic efficiency in Figs. 2–4 is based on partial equilibrium analysis. General equilibrium analysis models the interrelationships among markets, for example, accounting for impacts of changes in the price of oil that shift the demand for natural gas, shift the demand for vehicles, and shift the supply of transportation services, all of which in turn have effects that ripple throughout the economy.

Petroleum is a minor energy source in the residential and commercial sectors in the United States. Petroleum supplies 24% of the industrial sector, with ample room for substitutes, but petroleum supplies 97% of the transportation sector. Fuel cell technology is close to commercial viability and could be developed as a substitute for petroleum for transportation. Fuel cells would also substantially reduce urban air pollution. A policy to require that a fraction of sales be ultra-low-emission vehicles would speed the development of the infrastructure needed to commercialize fuel cells. A partial equilibrium analysis would deem a successful policy as a failure.

Whether based on hydrogen or natural gas-derived methanol, suppose a successful fuel cell program in 2002 results in transportation costs comparable to the price at that time—$30 per barrel of oil. Falling oil consumption would likely result in the collapse, or at least the diminishment, of the OPEC cartel market power. The resulting decline in oil prices could easily reach less than $10 per barrel, placing the fuel cells program politically at risk. Oil interests could commission partial equilibrium studies that show the fuel cells program to be an economic disaster at $30 per barrel, when in fact oil is at $10. Of course, the correct counterfactual for evaluating the fuel cells program would hypothesize oil prices in the context of a transportation sector without a substitute, requiring a computable general equilibrium (CGE) model with a cartel sector.

CGE models are routinely applied to environmental regulations to gauge the economic cost of policies to abate pollution. However, CGE models have not been modified to measure lost productivity from mortality, and ill-health effects of pollution causing worker absences or impairing human development, nor have they been modified so that increased medical expenses are measured as counterproductive rather than as adding to economic activity. Of course, the correct counterfactual for evaluating pollution abatement policy would correct CGE models to account for harm to human health, damage to agriculture and fisheries and forests, damage to vehicles and structures such as buildings and bridges, recreational losses, public good losses measured by contingent valuation studies, and so on.

2. CATEGORIES OF EXTERNALITIES: NATIONAL SECURITY AND POLLUTION

Although national security and pollution are the two most important negative externalities from energy production and consumption, neither should be estimated in isolation from the other. Most energy policies affect both national security and pollution.

2.1 Oil and National Security

Of the 68 million barrels of oil produced per day (mbd) in 2000, 30% were from the three top producers: Saudi Arabia (8.4 mbd), Russia (6.5 mbd), and the United States (5.8 mbd). This is changing because Iran, Iraq, Kuwait, Qatar, Saudi Arabia, and the United Arab Emirates hold 65% of the world's proven reserves, whereas the United States holds 2%. The United States consumes 19.7 mbd while producing 5.8 mbd, on net importing 70%. Of the total petroleum used in the United States, transportation use equals 68%. The transportation sector has virtually no substitutes for petroleum, which supplies 97% of all energy in that sector.

If externality abatement is subsidized through general taxes, the marginal cost of abatement is not necessarily equal to the optimal tax on the externality. As shown in Fig. 4, optimal policy design requires knowledge of both the demand for externality abatement and the cost of abatement. At the federal standard for ozone of 0.12 ppm, Fig. 4 depicts a marginal cost of abatement less than the marginal benefit. Another example is the national security costs of importing oil.

Broadman and Hogan identify three parts of an optimal oil import tariff: high oil prices that reflect monopsony power, adverse macroeconomic effects of higher oil prices on terms of trade, and the adverse impact of oil price shocks. Because the United States consumes 25% of world oil, the price depends on the amount consumed (monopsony power). The U.S. macroeconomy does not perform as well when oil prices are high, changing the terms of trade and requiring greater exports for the same amount of imports. The adverse impacts of oil price shocks are the basis of a 'security tariff' that can be calculated as the expected loss, equal to the product of the probability of an oil price shock from disruption of supplies multiplied by the negative impact of an oil price shock. The negative impact of an oil price shock can be estimated from the magnitudes experienced since 1970. The security tariff is interpreted as the willingness to pay for military protection of oil supplies, estimated in 1985 dollars to be equal to $7.00 per barrel (conditioned on the price of oil at $15/bbl). The axes in Fig. 2 could be relabeled so that the ordinate is in dollars per barrel and the abscissa is reduction in national security; thus, point N_C is complete security. Then the optimal tax, T_B, is $7.00 per barrel in 1985 dollars. The marginal cost curve in Fig. 2 would be the cost of additional security, including the cost of additional military preparedness and the cost of the strategic petroleum reserve.

Prior to the invasion of Kuwait by Iraq, the defense expenditures per barrel of imported oil plus the cost of the strategic petroleum reserve (SPR) were approximately $8.50 to $9.00 (in 1985 dollars) per barrel. I calculated the lost interest from storing oil, equal to the interest that would have accrued by investing the amount of money paid for the oil that was stored in the SPR; in 1985 $ the lost interest equals $1.15 per barrel of imported oil, and there is an additional $0.60 per barrel for the increase in the size of the optimal reserve from its inception to the mid-1980s. I also performed a time series analysis of defense spending and oil imports during the period from 1968 to 1989. After removing time trends and random walks, the data reveal a correlation between defense spending in each year to oil imports lagged two years, where one year of the lag accounts for the time delay between publication of oil import data and Congressional appropriations, and the second year of the lag accounts for the delay between appropriations and actual budget years. The result is an econometric estimate equal to $7.30 of defense spending per barrel of imported oil in 1985 dollars. Consequently, the marginal benefit calculated by Broadman and Hogan is close to the marginal cost I calculated, and one may conclude that in the 1980s the United States provisioned close to the optimal amount of national security related to importing oil. The price of oil did and does not include the national security cost, as it was and still is paid through general taxes rather than a tax on oil imports, and this national security subsidy for oil has the unfortunate consequence of economic inefficiency.

Certainly, the national security cost of oil imports is higher today. Macroeconomic effects of oil price shocks include less productivity, greater unemployment, and an increase in general inflation. Some oil revenue flows to terrorists and states acquiring weapons of mass destruction. Recessions have reverberating impacts on presidential elections. Presidents Carter and George H. W. Bush and Vice President Gore lost reelection following oil price spikes. In all three cases, the Federal Reserve Board responded to general inflation caused by oil price spikes by increasing the discount rate. Whether the recessions were caused directly by the oil price spikes or indirectly by the misdirected response of the Federal Reserve Board, the effect is the same: a recession during a presidential election.

2.2 Nuclear Power and National Security

Three types of terrorism are plausible. First, nuclear power plants and research reactors in the United States are potential targets for terrorists determined to release radioactivity. Second, increased trade in nuclear fuel and waste products provides more opportunities for sophisticated or government-sponsored terrorists to obtain the materials for a nuclear device. Third, dispersion of radioactive material throughout a city requires little sophistication and may not cause a large amount of much human and physical damage but would have a substantial psychological impact.

2.2.1 Attacks on Nuclear Power Plants

Attacks from the inside and outside are technically feasible, and the risk is growing. For example, Iran threatened on Tehran radio, "U.S. centers and nuclear reactors can be more vulnerable than the missile bases of the Islamic Republic of Iran." Approximately one-half of terrorism incidents occur in the Middle East, followed by Europe and Latin America, particularly Colombia (drug related) and Peru (the Marxist Sendero Luminoso). A substantial portion of international terrorist attacks are on U.S. interests. More than 300 metric tons of plutonium is generated annually, 45 of which is separated and suitable for weapons. In comparison, 6 kg of plutonium was used in the bomb dropped on Nagasaki. Plutonium separated from spent fuel is shipped to waste disposal sites. Some of this transport occurs on commercial airlines and by truck, train, and ship.

2.2.2 Diverting Nuclear Material: Nuclear and Dirty Bombs

Nuclear material is a threat if used to make a nuclear bomb or if spread by a conventional bomb. Nuclear bombs can be made from plutonium or highly enriched uranium. Plutonium is produced in plants that reprocess waste from conventional reactors. Natural uranium contains approximately 0.7% of the fissile isotope U-235. Conventional reactors use uranium slightly enriched to approximately 5% U-235. Low-enriched (to 20%) U-235 is used in research reactors. Highly enriched U-235 is a category higher than 20%, and weapons-grade U-235 is enriched to 90%.

India and Pakistan both produce enriched uranium; India also produces plutonium. These countries and others publicly embarked on programs to produce nuclear power, transferred the technology, and developed parallel programs to develop nuclear weapons. North Korea and Iran are openly pursuing this path.

2.2.3 Diverting Nuclear Waste: Poisoning Cities

Nuclear waste from breeder reactors includes plutonium-239, which is extremely toxic in minute quantities and has a half-life of 24,400 years. Low-level nuclear waste from conventional nuclear power plants includes cesium-137 and strontium-190, which are less toxic and have half-lives of approximately 30 years. Twenty half-lives is equivalent to 600 years, the time during which the waste poses a risk.

Unsophisticated terrorists, willing to accept exposure and death, could use nuclear waste to poison a city. The level of health risk from low-level waste may not be as great as that from an attack on a nuclear plant or from a bomb. However, the terror of exposure to nuclear radiation, no matter how low the dose, would still be considerable.

2.3 Pollution

Pollution occurs at every link in the chain from production to consumption: exploration, extraction, transportation, conversion, processing, consumption, and disposal. Pollution travels through environmental media, including tropospheric and stratospheric air pollution, surface and ground freshwater pollution, ocean pollution, and soil pollution. Damages vary across energy sources and uses, including human mortality and morbidity, reduction of ecosystem services to the economy, immiserization of the human spirit, and diminution of the intrinsic value of nature.

The objective of estimating the benefits of lower emissions is to determine, in economic terms, what damage society avoids by selecting one set of policy options over others. To determine this, the potential damages of emissions must be calculated. This involves the following:

1. Estimate the changes in emissions for all pollutants affected by policy changes.
2. Estimate the changes in ambient pollutant concentrations in all relevant environmental media predicted to result from changes in emissions.
3. Estimate the pollution transformation and transport to target.
4. Establish the exposure–dose/response relationships between ambient changes and health effects and impacts on horticulture, visibility, buildings/structures, etc. For human mortality and morbidity, this requires the additional intervening step of estimating changes in exposure and dose in the damaged population that would result from changes in ambient concentrations, where dose depends on body size, age, activity, and location affecting intake and internal concentration.
5. Calculate the level of effects projected.
6. Attach dollar values to the estimated effects.
7. Attribute dollar values to the pollutants that caused the damages or to the policy changes that reduced the damages.

There are various methods for accomplishing each of these steps, but each must be completed to calculate the economic value of a policy change. Each step represents a complex calculation that often violates economic assumptions, such as differentiability and convexity. All of the links in this chain present challenges and pose obstacles to consensus, as the following examples of urban air pollution and global warming illustrate.

2.3.1 Estimating Reductions in Emissions from Policies

Step 1 requires an inventory of all the types of pollutants affected by the policy options and the appropriate counterfactual with which to compare the policy. An example is regional air pollution caused by electricity generation. A seemingly straightforward policy is to hold a Vickery auction for renewable electricity generation of a certain number of megawatts, such as the auction held by the California Public Utilities Commission in 1994 (and rescinded the following year on the grounds that deregulation was impending and markets would best decide how much and what type of additional capacity to build). An electricity dispatch model is needed to calculate the change in emissions.

Power plants are typically dispatched in increasing order of short-run marginal cost until the system demand is met. As demand changes from off-peak to peak periods, the least expensive of the remaining plants is dispatched to meet load, subject to technical constraints, spinning reserve requirements to meet fluctuations in load, and a reserve margin to cover maintenance outage and unscheduled outages. Some plants cannot be shut down during the weekend and some have a minimum operating level. Some are slow-start plants and others are quick-start plants. Technical constraints determine the type of load each can serve.

The addition of power plants to a system alters all of the previous calculations. By accounting for the location of the units, one can calculate emissions for each airshed. The calculation of emissions is a direct function of the calculated dispatch order. Consequently, the emission estimates depend on the reordering of dispatch due to a change in the combination of power plants.

2.3.2 *Estimating Changes in Pollution Concentration*

Step 2 requires the application of a model to project how emission changes will alter ambient pollution concentration. This really has two parts; the baseline pollution concentration is forecast in the absence of the policy, and the altered pollution concentration is forecast conditional on the change in emissions. Fig. 6 provides an example of a baseline forecast of ambient CO_2, showing historical levels during the past 600 million years and projecting what could happen during the next 400 years based on consumption of economically available fossil fuels.

The Intergovernmental Panel on Climate Change uses 120 years as the e-folding time atmospheric residence for a pulse increase of CO_2 sufficient for $RCO_2 = 2$. RCO_2 is the ratio of CO_2 to the ambient concentration prior to the industrial revolution in the late 1800s. The e-folding time is the number of years at which the biosphere and ocean removes 63% of the increase from pre-industrial levels; so that if CO_2 were to instantaneously double and no additional emissions occurred, after 120 years ambient CO_2 concentrations would still be 37% higher. For increases greater than $RCO_2 = 2$, the e-folding time increases dramatically. Carbon uptake by plants is limited because biological material decays, releasing carbon. For example, at the Triassic–Jurassic boundary approximately 200 million years ago, CO_2 was so high that climate effects led to the disappearance of most species. Almost all models used by economists make the assumption of linearity, seriously underestimating ambient concentrations for a tripling ($RCO_2 = 3$) or more. At three times preindustrial concentrations, the e-folding time would be between 380 and 700 years. To model the atmosphere beyond a doubling of CO_2, the models used by economists are misspecified. For a tripling ($RCO_2 = 3$) or larger, the natural science literature assumes that 50% of the emissions remain in the atmosphere, as presented in three alternative baseline forecasts in Fig. 6B.

Three economic models, combined with the previously discussed assumption, predict baseline RCO_2 increasing to 9, 11, and 16. To get a sense of the scale involved, Fig. 6A shows atmospheric concentrations measured in RCO_2 during the past 600 million years. The macro models forecast that economic forces will cause, within the next 325–350 years, the atmosphere to revert to an era never experienced by most plants and animals living today—levels not experienced by Earth at any time during the past 375 million years.

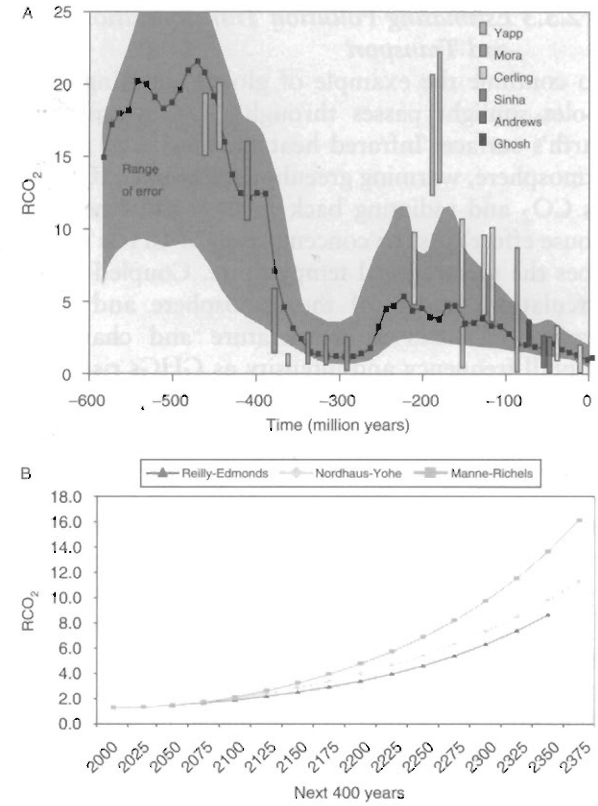

FIGURE 6 (A) Past atmospheric CO_2. Atmospheric CO_2 versus time for the Phanerozoic (past 550 million years). The parameter RCO_2 is defined as the ratio of the mass of CO_2 in the atmosphere at some time in the past to that at present (with a preindustrial value of 300 parts per million). The heavier line joining small squares represents the best estimate from GEOCARB II modeling, updated to have the effect of land plants on weathering introduced 380–350 million years ago. The shaded area represents the approximate range of error of the modeling based on sensitivity analysis. Vertical bars represent independent estimates of CO_2 levels based on the study of paleosols. Reprinted with permission from Berner, R. A. (1997). The rise of plants and their effect on weathering and atmospheric CO_2. *Science* 276(25), 544–546. Copyright American Association for the Advancement of Science. (B) Baseline forecasts of RCO_2. The rate of emissions over time is based on three macroeconomic models that link forecasts of future economic activity with the potential use of fossil fuels. In descending order of the growth rate for CO_2 emissions, the macro models are labeled MR, NY, and RE. MR refers to Manne, A., and Richels, R. (1990). *Energy J.* 11(2), 51–74. NY refers to Nordhaus, W., and Yohe, G. (1983). *In* "Changing Climate," pp. 87–153. National Research Council, National Academy Press, Washington, DC. RE refers to Reilly, J., Edmonds, J., Gardner, R., and Brenkert, A. (1987). *Energy J.* 8(3), 1–29. Accounting for all fossil fuels, the economically available fossil fuels vary between 8 and 17 metric teratons. The MR forecast assumes 17 metric teratons, NY assumes 12, and RE assumes 8. Reproduced with permission from Hall, D. C. (2001). *In* "The Long-Term Economics of Climate Change: Beyond a Doubling of Greenhouse Gas Concentrations" (D. C. Hall and R. B. Howarth, Eds.). Elsevier, Amsterdam.

2.3.3 Estimating Pollution Transformation and Transport

To continue the example of global warming, ultraviolet sunlight passes through CO_2, warming the earth's surface. Infrared heat radiates back into the atmosphere, warming greenhouse gases (GHGs) such as CO_2 and radiating back to the earth (the greenhouse effect). As the concentration of GHGs rises, so does the mean global temperature. Coupled general circulation models of the atmosphere and oceans project increases in temperature and changes in rainfall frequency and intensity as GHGs rise.

Natural scientists expect the ambient concentration of GHGs to double within the next 100 years (most likely by 2060). Natural scientists use a doubling as a convenience in the thought experiment: If concentrations double, what will be the impact on global average temperature? The answer, from coupled general circulation models (GCMs), is 1.5–4.5°C. For easier cross-discipline comparison, economists use the same benchmark, $RCO_2 = 2$.

If we confine the baseline forecast to a doubling of concentration, it may be reasonable to assume that Earth's systems return to equilibrium, as is done in one famous model (DICE, RICE, and derivatives). Most economists assume that the ocean captures a significant amount of heat, with an e-folding time of 500 years, so increases in deep ocean temperature decay back toward the preindustrial revolution level outside the time frame of any model. This specification is inconsistent with findings of ocean surface water temperatures. More problematic for analysis of $RCO_2 > 2$, the Atlantic Ocean thermohaline circulation may end, resulting in a new stable equilibrium for ocean and atmospheric circulation.

Figure 7 presents baseline forecasts of mean global temperature from a model that specifies an ocean thermal lag, where one-half of the radiative forcing is stored in the ocean for 50 years and then released. The three baseline forecasts show how global temperature forecasts depend on key assumptions regarding the sensitivity of the climate to increases in CO_2 and the amount of economically available fossil fuels. The ocean thermal lag is consistent with findings that from 1948 to 1998, the heat content of the top 3000 m of the oceans increased by 2×10^{23} J, corresponding to a warming rate of 0.3 w/m^2 or approximately one-half of the warming predicted by GCMs for the past century.

Based on a comparison among three GCMs, for a doubling of CO_2 equivalent gases, the models predict 12% greater warming for the United States than the global mean because the United States is at a high latitude. As the earth warms, the largest temperature changes will occur near the poles.

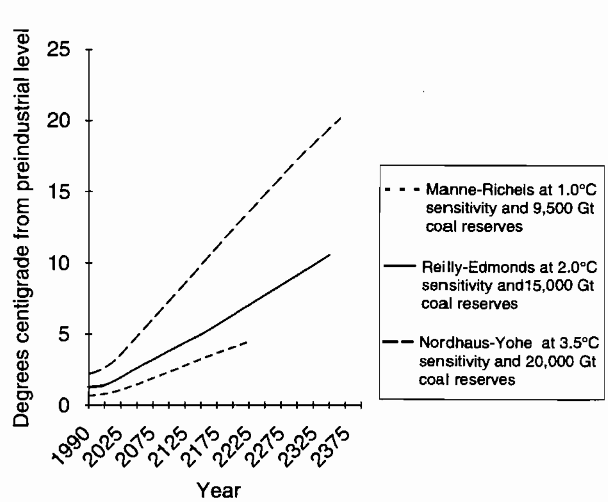

FIGURE 7 Mean global temperature increase.

2.3.4 Establishing Exposure–Dose/Response Relationships

Models of exposure–dose/effect relationships for air pollution are increasingly complex. Much of the past economics literature simply correlates air pollution concentrations with morbidity and mortality. One recent model calculates dose taking into account indoor, outdoor, and in-transit exposure; activity level that increases respiration; and body mass that changes with age. Exposure is measured in the REHEX model by time-weighted and location-specific ambient concentrations relative to indoor, in-transit, and outdoor activity for each age group and work status. Doses are integrated measures of pollutant intake. REHEX translates exposure into dose by accounting for activity and age. Dose is dependent on activity (e.g., work type) and age (children have higher metabolism and elderly people have lower metabolism).

Individual ill effects are identified in the health effects literature, with dose–response estimates that vary by age and health status. Effects range from eye irritation to hospitalization and death.

2.3.5 Calculating the Level of Effects

For some examples, such as climate change, the level of effects depends on the time frame for the analysis. Moderate climate change, based on a doubling of GHG concentrations, benefits midlatitude and upper latitude countries with milder weather; milder weather benefits agriculture, forestry, shipping, and transport; milder weather lowers heating bills and makes surroundings more conducive to human activity.

Damage to midlatitude countries includes more frequent and severe droughts and storms, hurricanes, cyclones, rapid snowmelt, and flooding; increased costs for water transport, storage, and flood control; migration of pests and increases in agricultural pest damage and control costs; migration, spread, and ill effects of disease and increases in health care costs; higher cooling bills; damage to coastal cities; reduced aquaculture yields; damage to coastal ecosystems and wetlands; and beach erosion. Damages to equatorial countries will be severe, including immersion of island nations and coastal properties, river delta flooding and damage to wetlands, damage to agriculture, loss of life, the destruction of coral reefs worldwide and the fisheries and tourism dependent on them, and severe droughts and floods.

Tripling or quadrupling of GHG concentrations would have severe consequences for the global economy, human health, and just about every aspect of human endeavor. Frozen deposits of methane in ocean sediments could thaw, instantaneously releasing massive amounts of GHGs into the atmosphere. There may be several global equilibria of GHG concentrations in the atmosphere and oceans. Tripling or quadrupling GHG concentrations could cause Earth's climate to shift to a new equilibrium and to never return to the climate of today. A tripling of GHG concentrations within 150 years is consistent with several models of economic activity and concomitant fossil fuel consumption. The range of uncertainty for a doubling of GHG concentration is between 1.5 and 4.5 degrees warming of mean global temperature, but we are ignorant of the range of temperature increase if GHG concentrations were to triple, quadruple or quintuple. We have modeled the range of temperature increase that would result would result in a shut-down of the Atlantic Ocean currents that keep the climate mild in northern Europe, but we are ignorant of the GHG concentration necessary to warm intermediate ocean water and release catastrophic quantities of methane to the atmosphere.

2.3.6 *Attaching Dollar Values*

Valuing the adverse effects associated with energy involves estimation of the value people place on avoiding the identified effects. Many of the effects are nonmarket goods, such as damage to human health and loss of life. Dollar values for nonmarket goods can be derived indirectly from hedonic studies or directly through surveys using contingent valuation methods or their derivatives. Hedonic studies use market data to obtain values such as differences in wages to measure wage premiums paid in exchange for higher risk jobs. From these studies, economists calculate the value of statistical life (VSL). Contingent valuation surveys ask respondents how much they are willing to pay to reduce risks or avoid ill effects.

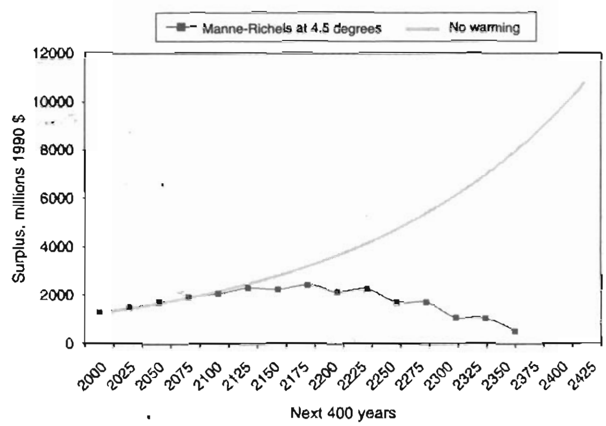

FIGURE 8 Agricultural surplus for wet climate.

VSL studies have recently been used to estimate the value of one life year. Assuming that the elderly are primarily at risk means that premature death from particulate matter (PM) is heavily discounted. When these biased estimates are corrected by including the risk of death to children, the estimated value of reducing particulates will increase, unless of course we use income stream over a lifetime and discount it. Then, the value of a child's life is much smaller than that of an adult at a prime earning age.

Valuation also requires the specification of a discount rate. With a rate greater than 3% (which is the minimum that many economists use), costs and benefits 100 years or more into the future are discounted to virtually zero in today's dollars and thus have virtually no impact on a benefit–cost calculation. For example, Fig. 8 shows an estimate of the time path of U.S. agricultural producer and consumer surplus in a scenario of climate change in which initially there are minor benefits from warming but ultimately agriculture in the United States collapses. With a discount rate of 5%, the present value of warming is greater than that of avoiding warming because the early minor benefits count more than the eventual collapse. If the discount rate is set to 1%, however, then economic valuation of the future years has significant weight to conclude in favor of avoiding collapse.

2.3.7 *External Costs of Pollutants and Benefits of Policies*

Step 6 requires knowledge of the precise relationships between ambient levels of all pollutants that derive from the initial emissions and the ability to separate the contribution of each pollutant to ambient changes.

A study estimated the value of meeting federal ozone and PM10 standards in the South Coast Air Basin of California. For this purpose, steps 2–6 were completed. Step 1 was omitted because the question was what the benefits would be of meeting the standards, so the assumption was that emissions would be reduced enough to meet that objective. Step 7 was also omitted because there is no scientific or economic foundation for allocating inputs among joint products or for attributing products to non-depletable inputs. Another study based on the same methodology followed steps 2–5 for the purpose of projecting the pattern of exposure as emissions are reduced. These studies recognized the fundamental difficulties of evaluating a change in emissions relative to eventual damages, including the difficulties presented by the need to estimate air quality changes from emissions changes and to allocate damages back to emissions, and by the vast gap between what is known about the health effects of ozone and other pollutants and what can be quantified and valued in economic terms.

3. ESTIMATES OF EXTERNAL ENERGY COSTS

To understand the magnitude of negative external costs of energy, it is useful to aggregate and average over energy sources, comparing fossil fuels (coal, crude oil, and natural gas) with nuclear power, with solar power separately, and with solar power combined with natural gas to be operated as a baseload power plant. Aggregation in this sense can be easily misinterpreted as a set of estimated pollution taxes that would result in economic efficiency. This is not the case, as explained previously.

In Table I, the estimated externality values are in Year 2000 dollars, updated from previous studies using the implicit price deflator. The national security costs and carbon emissions can be directly attributable to specific energy sources. The national security costs of oil are the addition of national defense expenditures attributable to importing oil and the cost of the strategic petroleum reserve. Note that the national security cost of oil has not been updated to reflect events since 1990, so this estimate is low. The estimates for coal and nuclear power are specific to those energy sources. Numerous externalities have been omitted, particularly for coal, including water pollution, waste disposal, and wholesale destruction of ecosystems at mining sites. The air pollution damages from natural gas and oil, however, represent a sum total that has been attributed to the energy sources linearly, based on the proportions of specific air pollutants from each source.

Table I does not provide optimal taxes that will internalize the externalities. The economic theory of externalities, depicted in Fig. 1, shows a tax on output that coincides with the units of measurement in Table I, whereas Fig. 2 shows a tax on externalities that would have units of measurement in dollars per pollutant. Even if the values were reported in dollars per pollutant, such calculations are illustrative only because of nonconvexities (e.g., NO_x is a nondepletable catalytic pollutant that converts into both ozone and particulate) and the inability of models to capture subtle effects that cascade between natural and social systems.

TABLE I

External Costs from Pollution and National Security[a]

Energy source	Private cost market price 2000 $	External marginal cost					Social marginal cost
		Subsidies	Carbon emissions	Air pollution	Other externalities	National security	
Natural gas ($/mmbtu)	5.80	—	0.24	0.39	—	0	6.46
Crude oil ($/bbl)	29.50	—	1.92	14.88	—	12.70	59.20
Coal ($/ton)	31.70	—	9.05	17.98	—	0	58.73
Nuclear($/MWh)	6.75	1.80	0	0	1.80	0.12	8.68
Solar thermal ($/MWh)	9.51	0	0	0	—	0	9.51
Baseload solar and gas ($MWh)	5.80	0	0.14	0.22	—	0	6.16

[a]Source: Calculated from Hall (1990, 1992a,b) using the implicit price deflator for the Year 2000 relative to previous estimates.

Table I demonstrates that external costs of coal and oil are at least double the price; natural gas and nuclear power have much lower external costs than coal and oil; and the major problem with nuclear power is the private cost of building, maintaining, upgrading, and operating power plants and waste disposal. It is also clear from Table I that in the southwest United States thermal solar power with natural gas backup as a baseload unit has a lower social cost than nuclear power.

4. POLICY CHOICES

There are five aspects to good economic policy analysis. One is to consider all aspects of economic efficiency that policies affect. The second is to recognize when static economic efficiency arguments are not applicable due to misspecification of the alternatives, nonconvexities, nondepletable pollutants, uncertainty, timescale, and ignorance. The third is to incorporate the dynamic efficiency criterion in the context of state dependency of technology. The fourth is to consider policy strategies that increase flexibility and diversity to reduce macroeconomic risk. Finally, the fifth is to analyze wealth distribution effects of policies that determine political viability.

4.1 Evaluating All Market Failures That Policy Choices Affect

Externalities include benefits and damage from climate change. Many policies that would reduce emissions of GHGs would also reduce other forms of pollution caused by energy production and consumption, and some policies would also alter national security risks. Similarly, many policies that reduce regional air pollution also reduce water pollution, national security risks, and externalities from global warming. Policies to encourage investment in energy efficiency also address other forms of market failure, such as asymmetric information. Policies with joint benefits require benefit estimation that is inclusive and not exclusive; this is obvious, but it is rarely done in the economics literature.

Standard incentive-based policies include pollution taxes; tradable permits; hybrid combinations of long-term tradable permits with repeated, short-term permit sales; and permits tied to direct regulation of emission limits. These policies are evaluated with the static economic efficiency criterion but do not address some of the market failures associated with underinvestment in energy-efficiency technologies.

Studies show internal rates of return >20% on commercial applications of energy-efficient lighting ballasts, whereas interest rates are much lower. These market imperfections—adverse selection, high transaction costs, principle agent problems, and intrafirm information flows—result in economic inefficiency. Specifically, asymmetric information exists between ballast sellers and potential buyers for improvement in quality, resulting in a lemons market and adversely selecting the lower quality (at the lower price). Because separate meters do not exist for each use of electricity, and a single meter is used to calculate electricity bills, businesses have a high cost of evaluating the efficiency of appliances. One principle agent problem occurs when commercial buildings are leased, the owner is the agent for the lessee (the principle) in the purchase of fluorescent lighting, and asymmetric information exists between the principle and the agent regarding the replacement costs. Another principle agent problem occurs when the renter is not separately metered, but rather the owner pays the electric bill and the renter and purchases the lower priced and inefficient appliance.

There are three additional sources of market failure for energy efficiency investments. First, electricity customers face higher borrowing rates for energy efficiency investments than the interest rates faced by electricity producers to invest in additional supply. Second, retail rate design for electricity and natural gas is based upon short-run marginal costs rather than long-run marginal cost rate, so that rates encourage investment in energy efficiency only up to the point that the capital and operating cost of the energy efficiency investment is cheaper than the operating cost of energy production. Third, there are negative externalities in energy production that are avoided by energy conservation. If the borrowing costs are lower for electricity producers than electricity efficiency investments by electricity consumers, or if the electricity is priced equal to short-run marginal cost of production, then at the margin electricity consumers will not invest in efficiency even when it is less expensive than the marginal cost of building and operating additional power plants.

4.2 Policy Options and the Static Efficiency Criterion

Policy options include direct regulation (or pejoratively, command and control regulation) and incentive-based approaches, including pollution taxes and tradable permits allocated to polluters. Direct regulation includes requirements for pollution permits that polluters install the best available control technology when rebuilding power plants. Pollution taxes have fallen out of political favor, and may have constitutional challenges because the optimal pollution tax may vary over time and each tax adjustment could legally require congressional approval. Tradable permits give the holder the right to pollute a certain amount, to buy permits if emissions increase, and to sell permits if emissions decrease. One version of tradable permits is to lease the permit at a market auction. The so-called property rights solution is to allocate tradable permits in accordance with past levels of pollution, in essence appropriating common property and giving the property right to the polluter, without a corresponding property tax or any recognition of the economic rent.

If the property right to cause the externality resides with the party causing the damage, then the WTP is the correct marginal benefit curve. If the property right resides with the damaged party, the WTA is the marginal benefit curve (see Fig. 2). Solutions proposed by economists imply different allocations of property rights. Pollution taxes retain the property right for the public. Tradable permits, whose allocation is based on past levels of pollution, allocate the property right to the polluter. If tradable permits are leased at auctioned prices, the public retains the property right. When the U.S. Environmental Protection Agency changed direct regulations so that dirty power plants no longer had to be retrofitted to reduce pollution, the property right shifted from the pollutee to the polluter, and the marginal benefit curve was reduced by fiat, from the WTA to the WTP in Fig. 2. There is no unique optimal level of externality abatement without assuming who should own the property right, a normative issue.

Modern economic analysis favors the property rights solution to negative externalities. This selection is based on the criterion of static economic efficiency applied to Fig. 2. The solution requires setting the permitted amount of externalities equal to $N_C - N_P$, and polluters will trade permits if they can reduce pollution at a marginal cost less than the price of the permit. The result will be N_P abatement and the equilibrium price of the permit equal to the optimal pollution tax, T_P. This solution avoids the cost of direct regulation inherent in having regulators determine the cost of technology—a job best left to the market.

The property rights solution is an obvious misnomer since the other solutions—taxes, direct regulation, and auctioned leases of tradable permits—all have property rights retained by the public. Because the tradable permits are not subject to property taxes, it is also a misnomer to refer to the right to pollute as private property. An alternative is to lease tradable permits, retaining the property right for the public; this is referred to as the common property solution, favored by a small but growing group of influential economists. The common property solution—leasing tradable permits to pollute $N_C - N_A$—results in N_A abatement and an equilibrium price equal to T_A in Fig. 2.

Both the property rights tradable permits and the common property tradable permits options do not result in efficiency unless the amount of permitted pollution depreciates over time so that abatement increases in accordance with the analysis in Fig. 3, with the marginal benefit of abatement increasing over time due to the public good nature of abatement and population growth, and the increase in the pollution concentration shifting the intercept of the marginal benefit.

More problematic for the tradable permit approaches is that they do not acknowledge the joint pollutants, nonconvexities, and subtle cascading effects among natural and economic systems that render marginal benefit and marginal cost curves irrelevant.

4.3 Dynamic Efficiency and State Dependence of Technology

Some new technologies show promise for reducing externalities from energy. If CO_2 can be economically captured, it could be stored in several ways. One idea is to release CO_2 at the bottom of the oceans, but ocean currents could recirculate it. A second approach is to inject CO_2 into depleted oil and gas wells, raising pressure to capture remaining oil and natural gas and leaving the CO_2 in an impermeable reservoir; Ontario Power Generation has purchased the rights to GHG emission credits of 9 million tons of carbon and plans to inject the gas into old oil fields in the United States. Another idea is to inject CO_2 into coal mines, displacing and capturing methane gas. A Norwegian oil firm is injecting CO_2 into a saline aquifer under the North Sea, where the carbon is sequestered by reacting with the salt.

The integrated gasifier combined cycle (IGCC) is a technology that might lead to economically capturing CO_2 by burning pulverized coal in the presence of steam, generating CO and hydrogen gas. The hydrogen can be used to operate fuel cells or burned to generate steam for electricity, and the CO can be catalytically converted to CO_2 and captured.

Fuel cells can chemically generate electricity from either hydrogen gas or methane gas. Some buses, trucks, and smaller vehicles are powered by fuel cells. Fuel cells can also be strategically placed to stabilize a transmission and distribution grid, avoiding urban air pollution emissions.

Infrastructure investments for energy supply and transportation—dams, power plants, pipelines, roads, and transportation networks—all have lifetimes in decades, even centuries. We can identify irreversible environmental damage of staggering magnitude lasting centuries, but natural science is unable to pinpoint how much pollution the earth's systems can sustain prior to triggering cataclysmic events. What is certain is that eventually we need to redirect the path of technological change.

In the 1960s, economists argued correctly that as rising market prices reflected scarcity of fossil fuels, the result would be substitution, new discoveries of fossil fuels, and technological change that reduced the cost of discovering, extracting, transporting, and converting fossil fuels to useful purposes. It is the success of these arguments that makes it clear that policies that encourage technologies such as the fuel cell, IGCC, solar thermal power, solar electric power, biomass, geothermal energy, ocean thermal energy conversion, wind power, and other substitutes for polluting fossil fuels will also lead to further improvements in fossil fuel technology because owners of fossil fuels have extraordinary wealth that can only be protected by research and development that furthers fossil fuel supply and use. Economic forces and institutional and political infrastructure lead to technological path dependency.

Direct regulation has an advantage over tradable pollution permits when evaluated by the dynamic efficiency criterion for selecting among policy options. Direct regulation can force technological change and can do so quite flexibly. An example is to require a fraction of sales to be zero- or ultra-low-emission vehicles, allowing vehicle manufacturers to trade the requirement among each other. Another example is to require a fraction of the power purchased by a utility to be generated by zero or lower polluting technologies, called a "set-aside" for renewable energy; this can be efficiently accomplished with a Vickery auction —such as the 1994 auction held by the California Public Utilities Commission and discussed above. Energy efficiency standards for building design, electric motors, appliances, heating, ventilation, refrigeration, and air-conditioning are also examples. Technology-forcing policies include pricing and tax subsidies of renewable electricity technologies, and renewable energy tax credits; rebates, low-interest loans, and subsidized electricity rates for efficient appliance purchases; and mileage standards for vehicles (CAFE standards).

4.4 Flexibility and Diversity to Reduce Risk

Policies that reduce macroeconomic risk can be designed by applying the concepts of flexibility and diversity to hedge against adverse outcomes. Consider that an electric utility sets spinning reserve requirements at least as large as the amount supplied by the largest power plant in operation. Grid operation derates transmission capacity to account for loop-flow feedbacks that would cause the entire grid to fail if the largest transmission line were to short. Backup capacity is always on call in the amount equal to the largest single link on which the system relies. Our macroeconomic performance has hinged on a single supplier of oil, Saudi Arabia, with no backup capacity except the strategic petroleum reserve.

Solar thermal with natural gas backup, wind power, and other renewable technologies provide both flexibility and diversity. The small size of renewable electricity generators, coupled with the speed with which they can be built, permits a close matching of supply and demand, reducing the need for substantial reserve margins for electricity supply. Technology-forcing policies for energy efficiency and alternative energy sources result in more available substitutes in the event that fossil fuel prices increase.

4.5 Political Viability and Wealth Redistribution

The argument against pollution taxes is that the size of wealth redistribution makes taxes politically unfeasible. This argument is simply wrong and has been proven so. The argument against marginal cost water rates was that it is politically unfeasible—witness the Tucson, Arizona, city council voted out en mass 1 year after implementing such rates in the 1970s. However, a two-part increasing block tariff for water rates, based on long-term marginal cost, is politically feasible for the city of Los Angeles. Similarly, a two-part pollution tax could be levied with a low or zero tax up to some amount, and a higher tax thereafter, providing three policy tools: the initial tax, the breakpoint, and the higher tax. Furthermore, pollution taxes could be designed to be revenue neutral, potentially leading to greater efficiency in energy use and in other sectors of the economy. It is easy to imagine pollution taxes offsetting tax credits for technology development, for example.

Other pollution-reducing policies meet similar resistance. Auctioning pollution permits would be more efficient than allocating them to existing polluters, the latter model being the most often followed in the United States. Any effort to implement such an auction scheme is met with effective political resistance. Ironically, allocation with no auction is a large-scale wealth-distribution scheme that favors polluters.

Wealth redistribution clearly affects the political feasibility of policy options. Dating back at least to "The Logic of Collective Action," economists have recognized that the interests of small, well-organized groups regularly outweigh the larger public interest. The argument against pollution taxes is often couched in terms of the regressive effect on the average family. This is a disingenuous means of diverting attention from the very substantial economic rents that fossil fuel producers and marketers currently collect while placing health and other environmental risks on the families.

5. CONCLUSIONS

Economic analysis is useful for informing policy choices but not capable of proving that any single policy choice is more efficient than another. To do so would require the analyst to have all the information about costs and benefits that precludes central planners from replacing markets in the allocation of resources. The laws of chemistry and physics result in violations of assumptions in the theory of externalities. Furthermore, economic efficiency as measured in benefit–cost analysis is a narrow measure of net human welfare that indicates nothing about the equity of one option compared to another. It is the most inclusive method economists have developed to date, but it still is not appropriate as the primary means of choosing among policies that have far-reaching implications for this and future generations.

This should not be taken as an argument to abandon economic analysis but rather to work closely with other social and natural scientists to improve our ability to more accurately, transparently, and fully represent and compare alternative energy futures.

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