RESULTS FROM THE TGAS MODEL

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IS THE FORECAST FOR CARBON TAXES FORECAST BY TGAS AN OUTLIER: WHY THE FORECASTS BY OTHER MODELS ARE TOO LOW

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INTRODUCTION

Disagreement is one of the few things on which all of the modellers that participated in EMF 12 can agree. This disagreement, which includes all aspects of energy demand, economic activity, and policy instruments, is summarized by the models' forecast of the carbon tax that is needed to achieve a given level of emission reductions. For example, the forecast for carbon taxes in scenario III, which calls for stable emissions by the US at 1990 levels in 2000, runs the gamut from $25 per ton of carbon to $360 per ton. The taxes forecast by the TGAS model to achieve a given level of emission reduction tend to be at the upper end of the range. For example, TGAS forecasts the $360 tax that is required to stabilize emissions in the US.

Consistent with the herding instinct in modellers, I investigate why the taxes forecast by the TGAS model are consistently higher than those forecast by other models. A comparison of model structures and results indicates that the level of aggregation used to simulate energy demand and a priori assumptions about consumer behavior and the malleability of capital are responsible for a large portion of the variation among models in the forecast for the carbon tax that is required to achieve a given level of emission reduction. Because there is no "correct" level of aggregation or a priori assumption about consumer behavior or capital malleability, no model is "better" than another. Nevertheless, choices regarding these aspects of the model make some models' forecast more reliable than others regarding particular aspects of emission reductions.

The effects of aggregation and a priori assumptions on a model's forecast for the carbon tax needed to achieve a given level of emission reduction are of more than academic interest.

The wide range of taxes that they forecast are of little use to policy makers. Policy makers need to understand the differences among models that generate this range and how model structures and assumptions qualify some models to examine aspects of emission reductions better than others. To help policy makers use the information generated by EMF 12, I attempt to identify the structures and assumptions in TGAS that cause its forecast for carbon taxes to fall near the upper end of the range forecast by the models that participated in EMF 12. Based on this comparison, I also attempt to identify issues associated with emission reductions for which the level of taxes forecast by TGAS may be a more reliable indicator of effort needed to achieve a given level of emission reduction.

THE LEVEL OF AGGREGATION

Energy is consumed by processes controlled by firms and households. No model can represent the conditions of and decision making process by individual households and firms. Some level of aggregation is necessary. Differences among models regarding two dimensions of aggregation affect the forecast for the carbon tax that is needed to achieve a given level of emission reduction. One dimension concerns the grouping of firms and households. Along this axis, the least aggregated models specify many types of households and firms. For example, the DGEM model represents 672 types of households and 35 producing sectors (Beaver, 1992). Further along this axis, several more aggregated models specify energy demand by five or six sectors; agriculture, industry, commercial, residential, transportation, and electric utilities. TGAS forecasts energy demand at this level of aggregation.

Another dimension of aggregation concerns the geographical grouping of firms and households. The level of aggregation used by models included in EMF 12 fall between two extremes. At the least aggregated level, models such as DGEM, Gemini, and TGAS group energy demand by firms and households at the level of a single nation. For example, TGAS specifies energy demand by 14 nations. At the most aggregated level, CETA groups energy demand by firms and households at the level of the entire planet. At an intermediate level of aggregation, most of the models used in EMF 12 group energy demand by firms and households of several nations at the level of a region. For example, GLOBAL 2100 aggregates energy demand into five regions; USA, OECD other than the USA, USSR, China, and the rest of the world (ROW).[1]

The geographical dimension of aggregation is the more important determinant of the differences among models regarding the forecast of the carbon tax that is needed to achieve a given level of emission reduction. For any given target of emission reductions, the carbon taxes forecast by models that aggregate energy demand by region (e.g. CETA, GLOBAL 2100, GREEN, ERM) tend to be smaller than the carbon taxes forecast by less aggregated models (e.g TGAS, IEA, Gemini).[2] In particular, the increase in aggregation from grouping energy demand by households or industries within a nation (national models) to grouping energy demand by households or industries by a region larger than a nation (regional models) is critical. The process of aggregating national information to regional information introduces assumptions about energy prices and elasticities of demand that tend to overestimate changes in energy prices caused by a carbon tax and the price responsiveness of consumers.

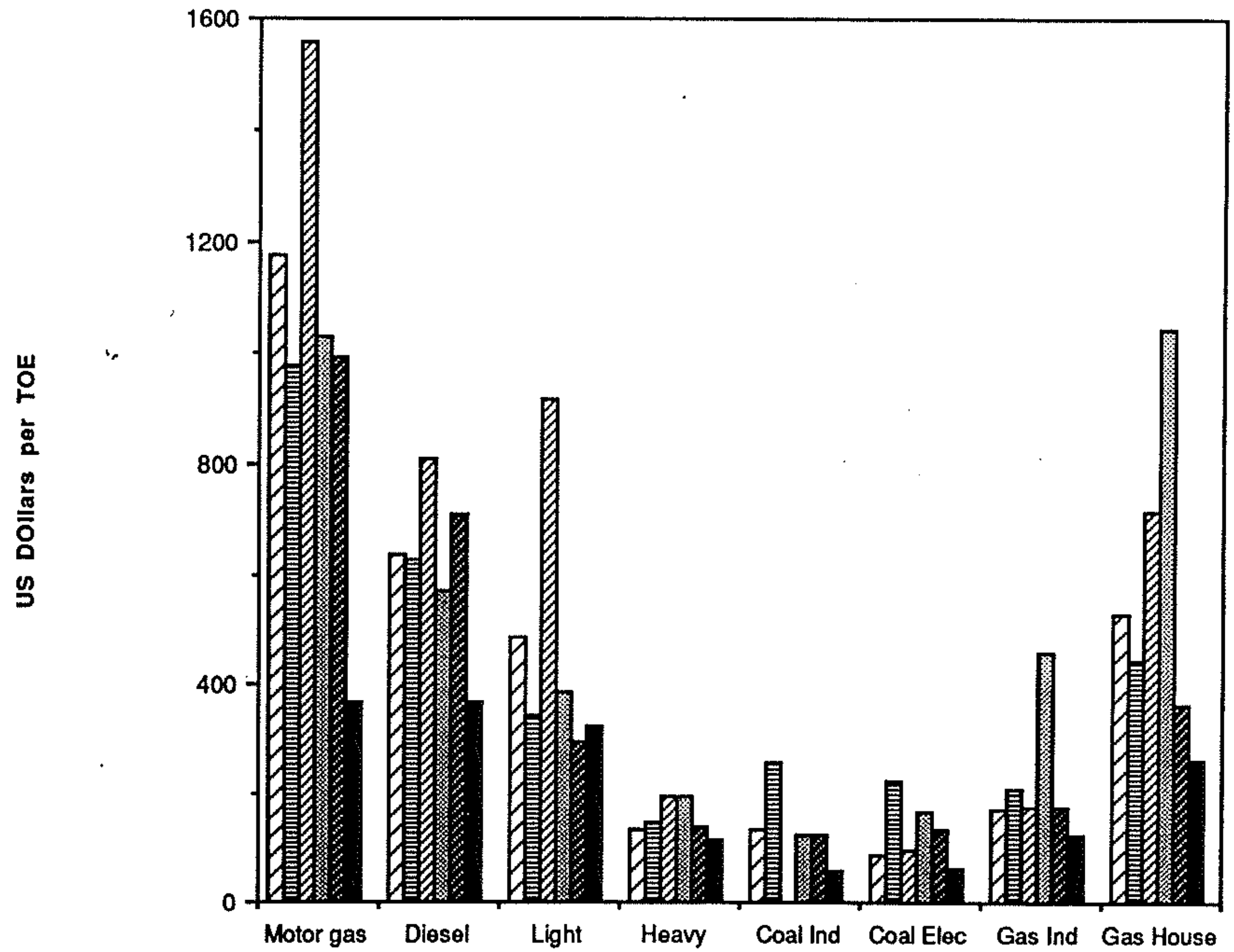
The Effect of Geographic Aggregation on the Specification of Energy Prices and Elasticities

All models indicate that the price of energy has an important effect on the amount of energy consumed (and carbon emitted) by firms and households. Energy prices can be measured at several points in the economy: the point of entry to the economy (the first purchase price); at intermediate stages of processing (the wholesale price); or at the point of final consumption (the end-user price).[3] The level of geographical aggregation affects the point at which the model measures energy prices. Because of their level of aggregation, national models can simulate the factors that determine price of energy to end-users by nation and sector. Conversely, the level of aggregation of regional models precludes the inclusion of such factors. As a result, regional models often measure energy prices at the point of entry.

The different points at which national and regional models measure energy prices is significant because international and sectoral differences in the price of energy increase from the point of entry to the end-user. While all nations pay nearly the same price for crude oil, the price for motor gasoline varies greatly among nations (Figure 1). These differences are generated by variations in the first purchase price, local taxes, and profit margins. Taxes are responsible for the largest fraction of the difference in the end-user price of energy among nations. Existing taxes vary greatly among nations. In general, OECD nations in Europe and Japan impose the highest level of taxes. For example, taxes account for more than 73 percent of price for motor gasoline in France and Germany in 1991 while taxes account for 37 percent of motor gasoline prices in the US (Energy Prices and Taxes, various years). As a result, the price of motor gasoline is nearly 4 times higher in France and Germany.

Differences in profit margin are another cause for differences in end-user prices. especially among sectors for the same fuel. For example, the refinery margin on motor gasoline tends to be the highest while the refinery margin on residual fuel oil often is negative. That is, the price of a barrel of residual fuel oil is less expensive than a barrel of crude oil. As a result, the pre-tax price of motor gasoline tends to be considerably larger than the pre-tax price of other refined petroleum products. Similar differences exist in the end-user price for other fuels. In general, the end-user price for natural gas purchased by the residential sector tends to be considerably higher than the end-user price for natural gas purchased by the industrial or commercial sector.

Figure 1


US DOllars per TOE
1600
1200
800
400
0
Motor gas
Diesel
Light
Heavy
Coal Ind
Coal Elec
Gas Ind
Gas House

Variations in the end-user price for energy among nations also are caused by the differences in the first purchase price. The greatest differences in the first purchase price of energy exist in coal and natural gas markets. Many nations protect their local coal industry by limiting and/or taxing imports. For example, the price of coal to electric utilities in Germany ($223.7 per toe), which protects its domestic coal industry, is much larger the average for OECD Europe ($138.3 per toe). Similarly, the first purchase price for natural gas depends on its availability via pipeline. Natural gas is very expensive to transport by ship. As a result, the first purchase price of natural gas in Japan, which imports all of its natural gas via ship, is 34 percent higher than the price paid by European nations, which import natural gas via pipeline.

Regional models find it difficult to simulate the causes for differences in end-user prices because of their level of aggregation.[4] In theory, it is possible to calculate an end-user price for a fuel within a region by weighting nation specific end-user prices by the fraction of that region's energy demand that is consumed by a particular nation. But regional models cannot forecast changes in regional end-user prices accurately. Because regional models forecast energy demand by region, the weights used to aggregated end-user prices do not change over time. Holding the weights constant introduces an increasing amount of bias into the models as nations within regions change their portion of total energy consumption. To avoid the difficulties associated with calculating regional prices to end-users, regional models often use the first purchase price.

The level of aggregation used by regional models also affects the elasticities used to translate changes in energy prices to changes in energy demand. The availability of historical data for economic activity, energy prices, and factor inputs allows national models to be constructed with equations for energy demand that are estimated from the historical record for specific sectors. The functional form and econometric techniques used to estimate the equations vary greatly among models. The specification are chosen to capture the types and relative importance of behaviors that the modellers believe have the greatest effect on energy demand.

On the other hand, it is difficult to estimate equations for regional energy demand from historical data because data for regional prices and economic activity are not readily available. As a result, regional models often are built with equations that are based on the modeller's personal judgement regarding the types and relative importance of behaviors that affect energy demand. For example, personal judgement is used to generate the equations for energy demand in 8 of the 11 models that participated n EMF 12 (Beaver and Huntington, 1992). Assumptions include the size of income and price elasticities for entire regions, and autonomous increases in energy efficiency.

The Effect of Geographic Aggregation on the Size of Carbon Taxes

The different ways in which national and regional models simulate energy prices and price elasticities affect the size of the carbon tax that is required to a achieve a particular level of emission reductions. The tax forecast by regional models for a given level of emission reduction tends to be smaller than the tax forecast by a national model such as TGAS because: (1) a carbon tax increases the first purchase price of energy by a percentage greater than it increases the end-user price; (2) energy's own price elasticity of demand based on the first purchase price implicitly is larger than the same elasticity based on the end-user price; (3) first purchase prices miss important differences among sectors regarding the effect of a carbon tax on the end-user prices; and (4) first purchase prices tend to overstate interfuel substitution from oil to natural gas.

One of the most important causes for the smaller size of carbon taxes that are forecast by regional models is associated with a systematic difference in the effect of a carbon tax on the first purchase price of energy relative to its effect on the end-user price. As currently envisioned, a carbon tax will be levied as a charge on the amount of carbon emitted. The effect of such a tax on energy prices can be measured two ways, as an absolute increase in price or a percentage change in price. For any given tax, the absolute increase in the price of a particular type of energy (e.g. coal, oil, or natural gas) is about the same, regardless of the point at which the tax is imposed. A $100 carbon tax will add about $13 to the price of a barrel of crude oil or motor gasoline. On the other hand, the percentage increase in the price of energy that is generated by a carbon tax depends on the point at which the price of energy is measured (first purchase price, wholesale, retail) and the sector to which it is sold. Of the two changes in price caused by a carbon tax, the percentage increase in the price of energy is a more accurate indicator of the effect of a carbon tax on demand.[5]

Measuring the effect of a carbon tax on the percentage change in the first purchase price of energy instead of the percentage change in the end-user price introduces a systematic bias into regional models that tends to understate the tax needed to achieve a given level of emission reduction and distorts the comparison of carbon taxes forecast by national models such as TGAS and regional models. Because the price of energy generally increases from the first purchase to end-user price, the percentage increase in the price of energy that is generated by a carbon tax decreases from first purchase to end-user price. If regional and national models assume a similar level of price responsiveness by consumers, regional models will forecast a lower carbon tax because regional models measure the percentage change in energy prices by the first purchase rather than end-user price.

There is some evidence to indicate that the carbon tax forecast by TGAS is related to the point at which TGAS measures energy prices. A comparison of model results indicates that in many cases, the percent change in the first purchase price of energy that is generated by the relatively small tax forecast by regional models is similar to the percent change in the end-user price of energy that is generated by the larger tax forecast by national models. For example, the $75 tax forecast by GLOBAL 2100 to stabilize emissions in the US generates a 27 percent increase in the first purchase price of oil . This increase is similar to the 37 percent increase in the price of light oil and the 32 percent increase motor gasoline prices that is generated by the $360 dollar tax forecast by TGAS.[6]

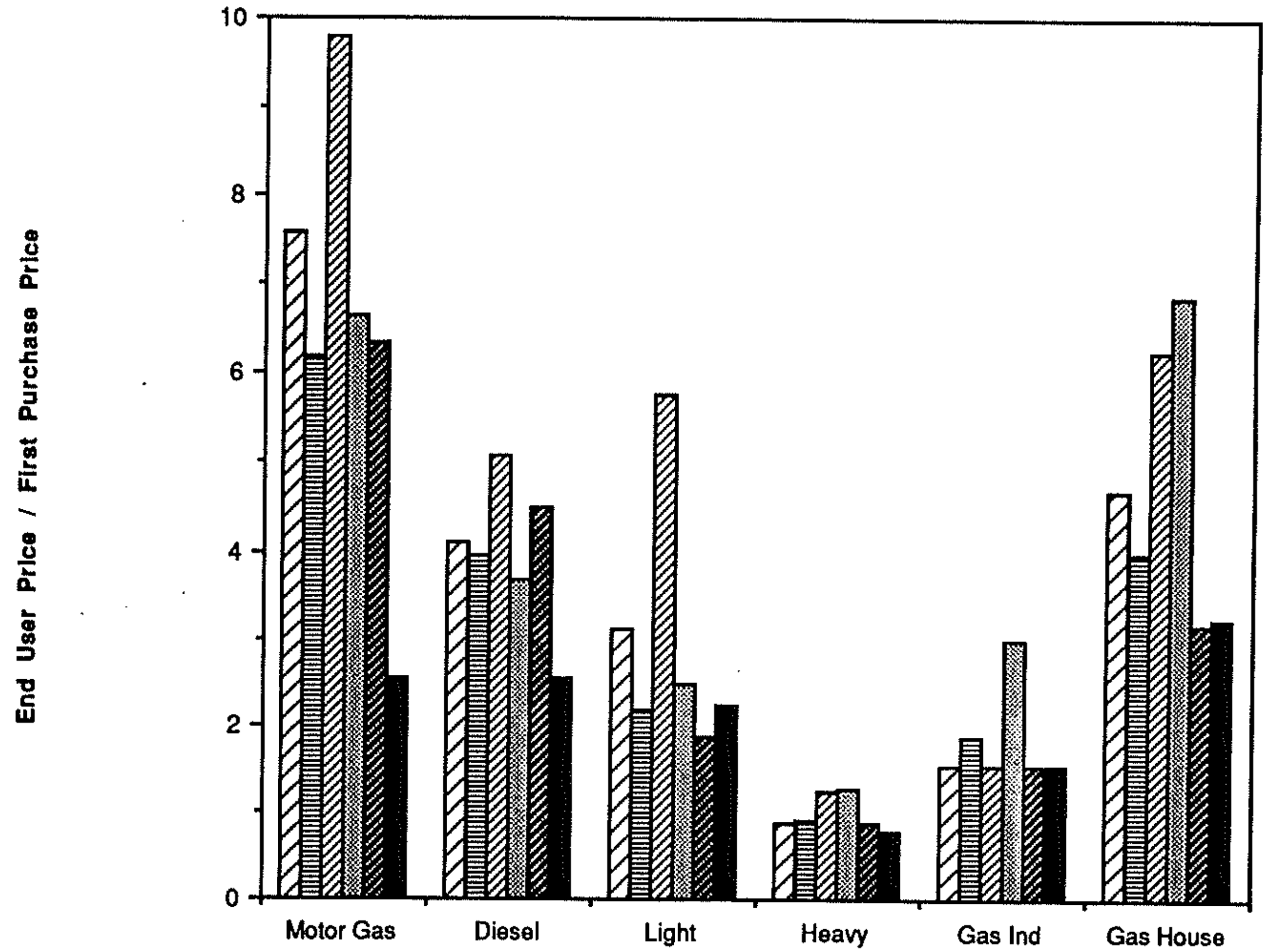
This similarity implies that a significant portion of the differences in taxes forecast by TGAS and regional models may be caused by the point at which energy prices are measured rather than differences in the way in which they represent the price responsiveness of consumers. To the degree that the difference in taxes can be traced to the point at which energy prices are measured, national models such as TGAS give policy makers a more accurate measure of the carbon tax that is needed to achieve a given level of emission reduction. Clearly, changes in energy demand and carbon emission are driven by the percent change in prices perceived by consumers, which are measured by end-user rather than the first purchase prices of energy.

Any similarity between the percentage change in first purchase prices that is generated by the tax forecast by regional models and the percentage change in end-user prices that is generated by the tax forecast by the national models may reflect an unintended effect pf using personal judgement to generate income and price elasticities. Judgement regarding the size of energy price elasticities of demand is influenced in large part by values reported in the literature. Nearly all of the elasticities reported in the literature are generated from analyses that use end-user prices to measure the price effect (Bohi and Zimmerman, 1984). For example, GLOBAL 2100 uses an energy price elasticity of 0.4 in the US and other OECD nations. This values seems reasonable because it falls within the range of values reported in many studies. Indeed, it is similar to the elasticities for coal, oil, and natural gas that were estimated in the process of building the TGAS model.

But regional models forecast the change in energy consumption that is generated by a carbon tax based on the percentage change in the first purchase price of energy. This procedure implies that the effective size of the elasticities used by regional models is larger than the value used in the equation for energy demand and reported in the model description. This increase is caused by the increase in the end-user price relative to the first purchase price. The end-user prices for most fuels are many times the first purchase price (Figure 2). The increased size of the end-user price increases the size of the elasticity by a similar proportion. This increase can be illustrated by the rise in the price elasticity for motor gasoline. Motor gasoline in Germany is 6 times more expensive than crude oil. If crude oil is $20 per barrel, a $100 carbon tax increases the price of crude oil 65 percent. An elasticity of 0.4 implies that a $100 carbon tax would reduce carbon emissions from motor gasoline 26 percent. But motor gasoline is 6 times more expensive than crude oil therefore, a $100 carbon tax increases the price of motor gasoline by only 10.83 percent. Because changes in motor gasoline consumption are influenced by the percent change in the price of motor gasoline rather than crude oil, the effective price elasticity for motor gasoline implicit in GLOBAL 2100 is 2.4 (26/10.83), or six times larger than the elasticity applied to the first purchase price.

Once the elasticities used by regional models are adjusted to reflect the difference between end-user and first purchase prices, the elasticities used by regional models tend to be much larger than those used by TGAS. Simple mathematics implies that the effective price elasticities used by regional models tend to be highly elastic (well over one). Such values fall near the upper range of value reported in the literature and usually are associated with long run adjustments to price changes (see section on capital malleability). The highly elastic price response that is implicit in regional model is another important reason that the taxes forecast by regional models tend to be significantly lower than those forecast by TGAS.

Figure 2



End User Price / First Purchase Price
10
8
6
4
2
0
Motor Gas
Diesel
Light
Heavy
Gas Ind
Gas House

The use of first purchase prices by regional models to represent the change in energy prices generated by a carbon tax causes a systematic difference between TGAS and regional models regarding the size of the tax needed that is needed to achieve a given level of emission reduction in the US relative to Europe and/or Japan. In general, the tax needed to achieve a given level of emission reduction in OECD nations other than the US that is forecast by national models is much higher than the tax forecast by regional models. For example, TGAS and IEA forecast that a tax of nearly $1000 dollars in 2000 is needed to reduce emissions 20 percent (scenario I) in OECD nations other than the US, whereas the tax forecast by all other models is below $200. This large difference is caused by a significant increase in the tax forecast by TGAS and IEA for OECD nations other than the US relative to the tax that TGAS and IEA forecast for the US. The increase in tax stands in stark contrast the forecasts generated by regional models, which indicate that the tax needed to achieve a given level of emission reduction in OECD nations other than the US is about the same or slightly less than the tax forecast for the US. For example, the ERM model forecasts that a $200 tax will reduce emissions 20 percent in both the US and OECD nations other than the US.

The increase in tax needed to achieve a given level of emission reduction in OECD nations other than the US that is forecast by national models is associated with a systematic difference in end-user prices among regions. The end-user price for most energies is several times larger in Europe and Japan than the US (Figure 1). The larger end-user prices for energy in Europe/Japan imply that for any percentage increase in end-user prices, the tax required for Europe/Japan is larger than the tax required for the US. For example, the carbon tax required to achieve a similar percentage increase in the price of motor gasoline throughout the OECD must be 2-4 time larger in Europe or Japan than the tax in the US because the price of motor gasoline is 2-4 time more expensive in Europe and Japan.

Regional models miss the need for higher taxes in OECD outside the US because they represent the effect of a carbon tax on energy prices via the first purchase price and they endow consumers in the OECD with a similar degree of price responsiveness. While the level of price responsiveness probably is similar between the US and the rest of the OECD, by definition, this similarity precludes the possibility that the tax needed to achieve a similar degree of emission reduction is similar between regions. To achieve the same change in end-user prices, which drive the change in energy demand and carbon emissions, the taxes for OECD nations other than the US must be significantly larger than those forecast for the US.

As a result, comparisons of the tax or level of emission reduction that are forecast by regional models for the US and other OECD nations are unreliable. Policy should be based instead on results generated by national models. If policy makers seek a similar degree of emission reduction in the US and other OECD nations, the tax must be higher outside the US. But a similar level of emission reductions may not be an economically efficient or politically acceptable. If instead, a uniform tax is applied to all OECD nations, policy makers should expect that the reduction in emissions by the US will be larger than that achieved by other OECD nations because the increase in end-user prices in the US will be larger.

Regional models tend to understate the tax required to achieve a given level of emission reduction because the effect of a carbon tax on the end-user price of coal, oil, and natural gas differs among sectors in a way that reduces the tax's effectiveness. Not only does the price of fuel increase from the first purchase to end-user price, but the size of the price increase for coal and natural gas varies by sector and the size of the price increase for oil varies among refined products. The largest increase in price from first purchase to end-users usually are associated with the largest sectors or most popular products. As a result, a carbon tax boosts the price of energy by the smallest percentage to the largest consumers. For refined petroleum products, a

$100 carbon tax in the US would have the smallest effect on the price of motor gasoline (a 26 percent increase in 1991), which accounts for 43 percent of US oil demand, and would have the greatest effect on the price of residual fuel oil (an 84 percent increase in 1991), which accounts for only 7 percent of US oil demand. For natural gas, a carbon tax would have the smallest effect on the price to households (20 precent in 1989), which accounts for 49 percent of UK natural gas demand in 1989 and have the largest effect on prices to the industrial sector (41 percent in 1989), which accounted for only 27 percent of UK natural gas demand in 1989. Overlooking the reduced effect of a carbon tax on the percentage increase in the price of energy to the largest consumers probably causes regional models to understate the tax required to achieve a given level of emission reduction.

Measuring energy prices by the first purchase price also causes regional models to overstate the importance of interfuel substitution, which causes these models to understate the size of a tax needed to achieve a given level of emission reduction. A carbon tax will impose the largest levy on coal, followed by oil and natural gas. These price increases will reduce emissions two ways. A carbon tax increases the price of fossil fuels relative to other factors of production, which will reduce emissions by prodding consumers to develop and implement production technologies and consumption patterns that substitute capital and/or labor for energy. A carbon tax also increases the price of fuels that emit large amounts of carbon relative to less polluting alternatives, which will reduce emissions by stimulating interfuel substitution from coal to oil and natural gas, and oil to natural gas.

The latter effect, substitution towards fuels that emit less carbon per heat unit, depends on the change in relative energy prices that is caused by the tax. A mathematical analysis by Kaufmann (1991) indicates that the direction and magnitude of substitution generated by a carbon tax depends on the carbon content and the pre-tax price of the energies. I found that a carbon tax may not always generate substitution away from energies with high a carbon content even though these energies are charged the greatest levy. A carbon tax may induce substitution towards a fuel that has a higher rate of carbon emission if the ratio of the price of the energy with the higher carbon content relative to the price of the other fuel is larger than the ratio of the carbon content of the fuel with the higher carbon relative to the carbon content of the energy with the lower carbon content. This relation is important because in some nations and sectors, the ratio of the end-user price of oil to natural gas is larger than the ratio of the carbon content of oil relative to natural gas. Under these conditions, a carbon tax induces substitution from natural gas to oil and increases carbon emissions. The results from TGAS indicate that this unanticipated direction of substitution occurs relatively often. The ratio of light oil to natural gas prices in the industrial sectors of Germany, Italy, and the US are such that a carbon tax will induce substitution away from natural gas to light oil. The increase in carbon emissions that are generated by these perverse changes in relative prices are significant because the industrial sector accounts for one third of these nations' demand for natural gas.

Regional models tend to overlook substitution from natural gas to oil because they measure energy prices by the first purchase price. In general, the percentage increase in oil prices from the first purchase to end-user prices is larger than the percentage increase in natural gas prices. This implies that the price of oil relative to natural gas measured by the end-user price is larger than the price of oil relative to natural gas measured by the first purchase price. The increases in the price of oil relative to natural gas measured by the end-user price implies that regional models overstate the increase in the price of oil relative to natural gas that is generated by a carbon tax. This bias overstates the reduction in emission that is caused by substitution of natural gas for oil and is responsible in part, for the lower tax forecast by regional models relative to TGAS.

THE IMPORTANCE OF A PRIORI ASSUMPTIONS

All models make a priori assumptions, either explicitly or implicitly. The models included in EMF 12 adopt very different assumptions about consumer behavior and the malleability of capital. These assumptions cannot be viewed as correct or incorrect nevertheless, they affect a model's forecast of the tax needed to achieve a given level of emission reduction. In general, econometric models such as TGAS make very few a priori assumptions explicitly. Implicitly, they assume that the market tend towards equilibrium and that the responses that they estimate from historical data represent the speed at which the market moves towards that equilibrium. Conversely, general equilibrium (GE) models assume that the economy moves towards and reaches equilibrium. To do so, GE models e make several explicit a priori assumptions about consumer behavior and the malleability of capital.

Different assumptions among models generate systematic differences regarding the speed and degree of adjustment to changes in energy prices that are generated by a carbon tax. Because econometric models do not force to economy to reach equilibrium, they tend to simulate partial adjustments that occur over a short period. Conversely, GE models simulate long run adjustments because they force the economy to reach equilibrium. As a result, econometric models require a larger tax than GE models to achieve a given level of emission reduction. The effect of these differences is best illustrated by comparing assumptions regarding consumer behavior and the malleability of capital.

Consumer Behavior

A priori assumptions about consumer behavior have a large effect on the size of a carbon tax needed to achieve a given level of emission reductions. Econometric models make a priori assumptions about consumer behavior that differ significantly from GE models. GE models often assume that consumers are perfectly rational, have perfect foresight regarding energy prices and the availability of alternative technology, and are intertemporal optimizers. Econometric models minimize a priori assumptions about consumer behavior. Most econometric models do not represent consumer behavior explicitly. Instead, consumer behavior is determined by the choice of independent variables and becomes embodied in the regression coefficients that are estimated from historical data.

Differences in the way in which models represent the formation of expectations about energy prices and the way in which consumers use these expectations to choose among energy technologies are an important source of differences among models regrading the the size of a carbon tax needed to achieve a given level of emission reductions. A priori assumptions about consumer behavior that are used by GE models to forecast energy demand allow consumers to make the "best decision" when confronted with a change in energy price. This "best choice" enables consumers to reduce energy consumption significantly relative to "sub-optimal decisions" chosen by econometric models. For example, the GLOBAL 2100 model indicates that perfect foresight and inter-temporal optimization by US energy consumers would have reduced US energy consumption in 1980 by 15 percent relative to the actual value (Manne and Richels, In Press).

The ability to foresee changes in energy prices and the willingness to act on this information in a way that maximizes the net present value of profit or utility minimizes the carbon tax that is needed to achieve a given level of emission reduction. If policy makers are to use the tax levels that are forecast by GE models as a guide for achieving reductions in the real world, policy makers must ask whether consumers behave in the manner assumed by GE models. Empirical evidence indicates that consumers do not; consumers are not perfect calculators and do not optimize over time, especially in regard to energy use. Hausman (1979) finds that either; (1) consumers do not maximize utility when they purchase air conditioners, or (2) they have a discount rate that is significantly larger than the social discount rate. Consistent with this result, Wirl (1991) finds that the regression coefficients associated with perfect foresight of prices are statistically significant but have the wrong sign when estimated a dynamic partial adjustment model. If these empirical analyses are coirrect, the inability or unwillingness to make the optimal decision when confronted with a change in energy prices increases the size of the carbon tax needed to achieve a given level of emission reduction relative to the forecast generated by GE models.

This does not imply that the assumptions and forecasts made by econometric models are superior. Many econometric models make an equally untenable assumption regarding consumer behavior. Most econometric models do not include the effect of expectations regarding energy prices on energy demand, and therefore assume implicitly that consumers do not consider future prices when they purchase energy using capital. TGAS is a notable exception to this generality. TGAS simulates the effect of energy price expectations on energy demand. The results indicate that the size of the tax needed to achieve a given level of emission reduction depends on how well consumers anticipate changes in energy prices and how they use such information when they purchase energy-using capital.

The lack of data for expected energy prices and mathematical difficulties associated with an empirically opertionalizable specification to represent their effect on investment decisions regarding energy using capital are important barriers to estimating the effect of forward looking behavior on energy consumption. GE models assume that consumers have perfect foresight regarding energy prices. This assumption implies that energy demand at time t could be correlated with energy prices at time t+n, where n s some positive number. But the assumption or perfect foresight overstates greatly, the ability of consumers to anticipate changes in energy prices. The severe recession in Houston and other "oil based" cities following the collapse in oil price is proof positive. The real-life inability to foresee oil price perfectly tends to increase the size of a carbon tax needed to achieve a given level of emission reduction forecast by econometric models relative to GE models. If consumers do not foresee changes in energy prices perfectly they may be unwilling to maximize utility or profits over time as if they could.

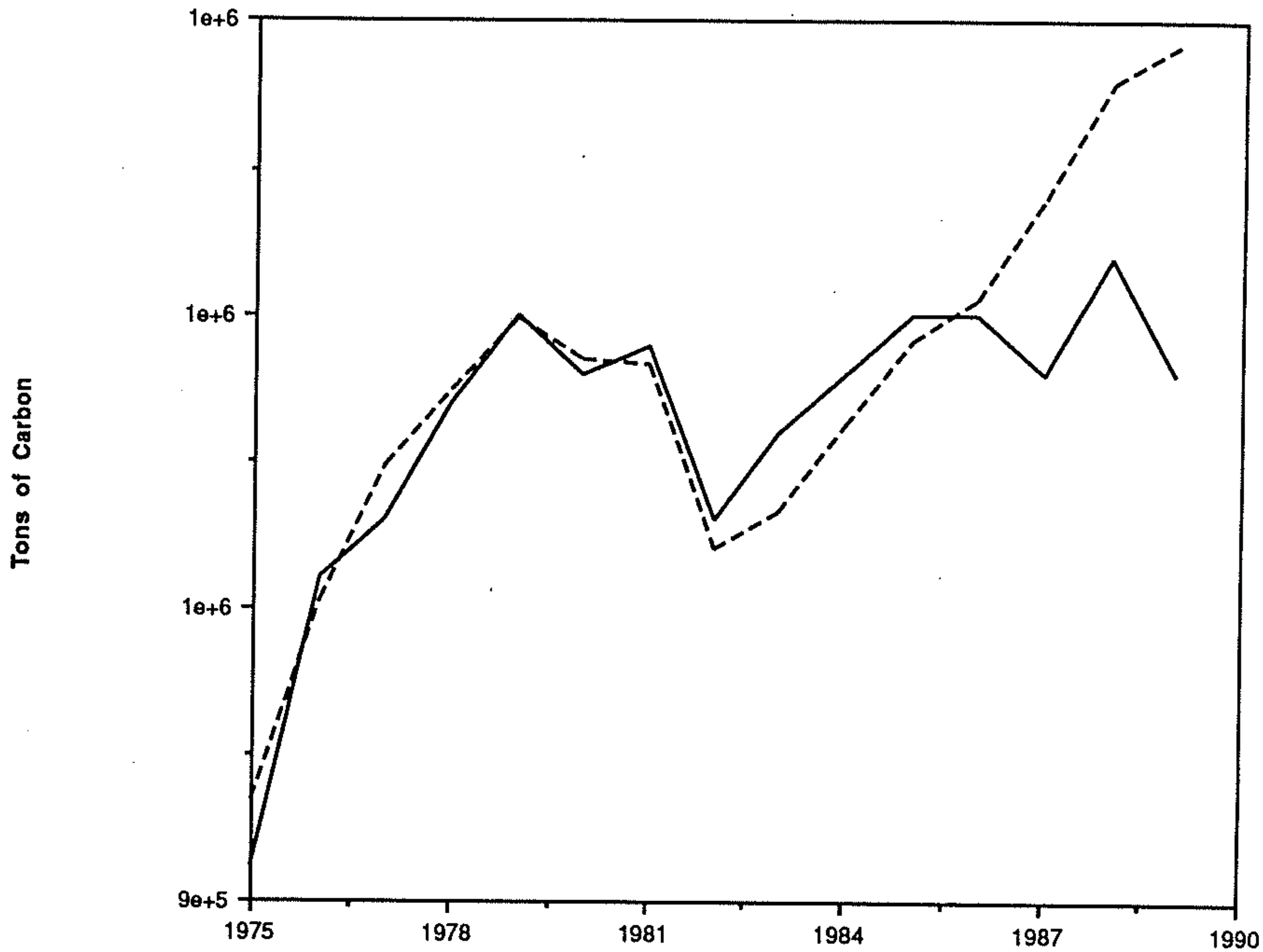
To relax assumptions about the ability of consumers to anticipate changes in energy price perfectly, it is possible to generate data for expected prices from previous observations using several techniques described by Pesaran (1987). Despite their mathematical sophistication, empirical analyses indicate that the expectations generated by mathematical techniques do not correlate closely with those held by energy consumers (Kaufmann et al., In review). To avoid this difficulty, the data for expected energy prices used to estimate TGAS are compiled from the forecast for oil prices that is published annually by the Department of Energy (DOE, various years). From these data, I can calculate the rate at which consumers expected oil prices to increase over various horizons. For example, I assemble data for the rate at which real oil price are expected to increase over a one year horizon by comparing the current oil price with the forecast for oil prices one year in the future for each of the forecasts published by DOE between 1975 and 1991. This process is repeated with data two, three, four... ten years into the future. By compiling these forecasts, I generate a time series for the rate at which consumers expected oil prices to rise one year into the future, two years into the future, three years into the future, etc. for each of the years between 1975 and 1991.

A second obstacle to the inclusion of energy price expectations on energy demand is a specification that can be estimated empirically from historical data. GE models avoid such difficulties by assuming that implicitly assume that consumers are certain about that future energy prices. This certainty allows the model to simulate profit maximizing decisions based on perfect foresight. In reality, consumers are most certain about current prices and tend to become increasingly uncertain about energy prices further into the future. Even small levels of uncertainty about future levels of energy prices reduces the willingness of use these expectations to invest in energy efficient capital that would maximize utility or profit over time (Fox-Penner, date). This implies that even if consumers are inter-temporal optimizers, the increasing uncertainty about energy prices in the future reduces their ability to make optimal decisions.

TGAS uses a simple specification to model the effect of energy price expectations on energy demand. The desirability of investing in energy efficient capital is represented by comparing the rate at which oil prices are expected to rise with interest rates. If real oil prices are expected to rise at an annual rate that is larger than real interest rates, the extra expense of purchasing energy efficient capital will generate a favorable return by reducing energy costs in the future. Such purchases tend to reduce rates of energy consumption. On the other hand, if oil price are expected to rise at an annual rate that is lower than interest rates, the extra expense of energy efficient capital will not be offset by lower energy costs in the future. Under these conditions, the extra expense for energy efficient capital could earn a higher return in other investments. The tendency to forego purchases of energy efficient capital would increase energy consumption.

The empirical data for expected prices and the simple specification allows TGAS to estimate the effect of price expectations on energy demand while relaxing some of the a priori assumptions about consumer behavior made by GE models. The econometric results indicate that expectations about energy prices have a significant effect on demand and carbon emissions. Historically, the effect of price expectations on energy demand is illustrated by holding the difference between the annual growth rate for expected oil prices and interest rates at their sample mean and comparing the forecast for emissions with the historical record. The results indicate that TGAS systematically underestimates carbon emissions between 1981 and 1985 and overestimates emissions between 1986 and 1989 (Figure 3). This error is associated with changes

Figure 3



in the difference between the annual growth rate for expected oil prices and interest rates. Although energy prices were relatively high in the early 1980's, consumers did not purchase energy efficient capital consistent with this price level because consumers expected oil price to rise less rapidly than interest rates (Figure 4). On the other hand, real oil price were relatively low after 1986. This decline in real oil prices did not cause carbon emissions to rise rapidly because consumers expected prices to rise faster than interest rates (Figure 4).

Similarly, results from TGAS indicate that the way in which consumers form expectations about the change in energy prices that is generated by a carbon tax affects the ability of the tax to reduce emissions. A carbon tax that stabilizes emissions loses much of its effectiveness if the increase in the energy prices over time that is generated by the carbon tax is not anticipated fully by consumers. If the tax that stabilizes emissions in the US is imposed as described in scenario III, but consumer behavior is changed such that consumers form their expectation of future energy prices on the belief that the tax will remain at its current level, emissions in 2010 are 5 percent higher than the case in which the effect of the increasing tax on energy prices is anticipated fully (Figure 5). If consumer behavior is changed such that consumers form their expectation of future energy prices on the belief that the tax will be removed, emissions in 2010 would be 13 percent higher than the case in which increases in the tax are anticipated fully (Figure 5).

The importance of expected energy prices on both past and future rates of carbon emissions indicate that the ability of consumers to anticipate changes in energy prices and their willingness to act on these expectations has an important effect on the level of taxes that is needed to achieve a given level of emission reduction. A small tax is needed to achieve a given level of emission reduction if consumers have perfect foresight and use this information to optimize over time. The foresight and willingness to act on expectations indicated by TGAS probably are

Figure 4

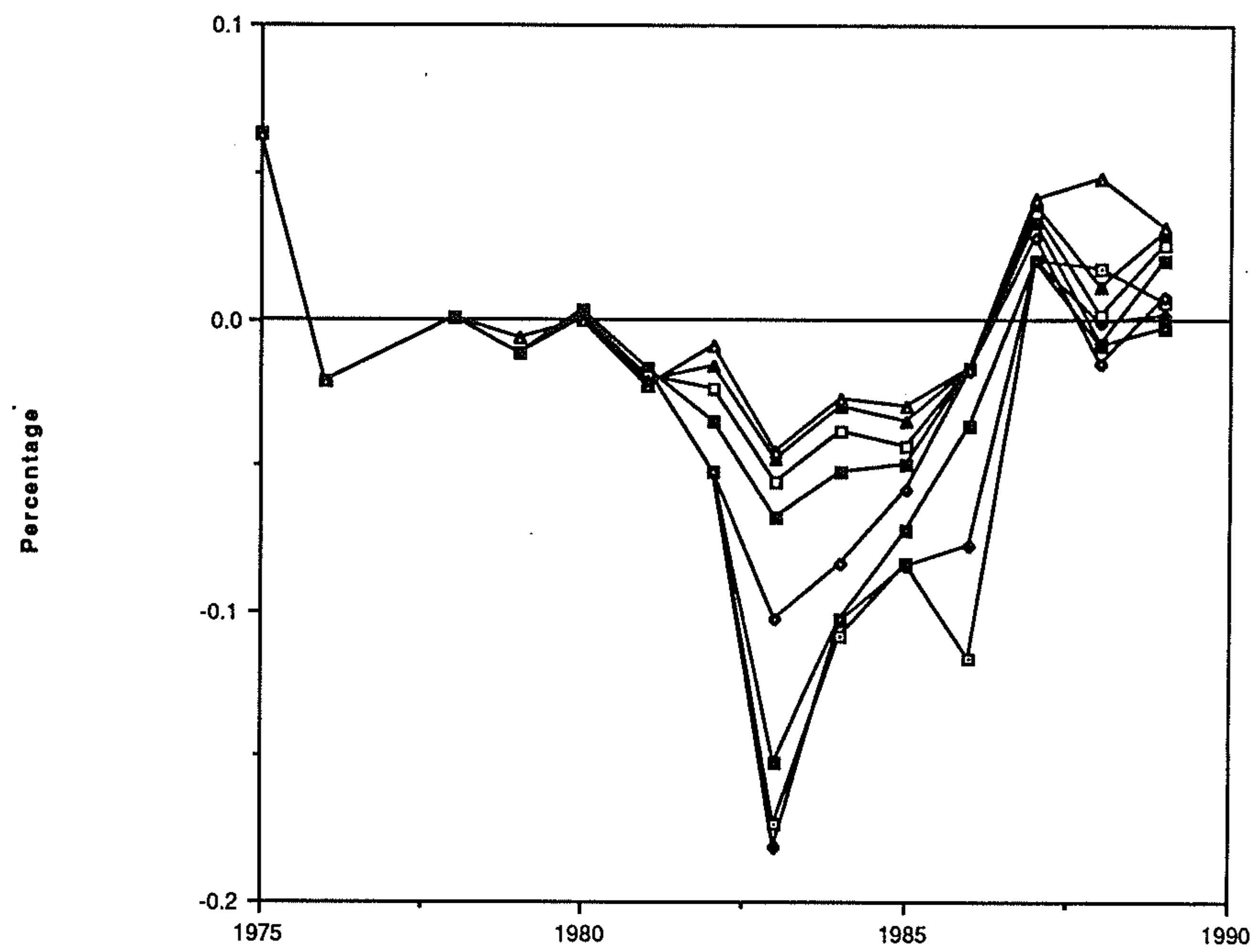
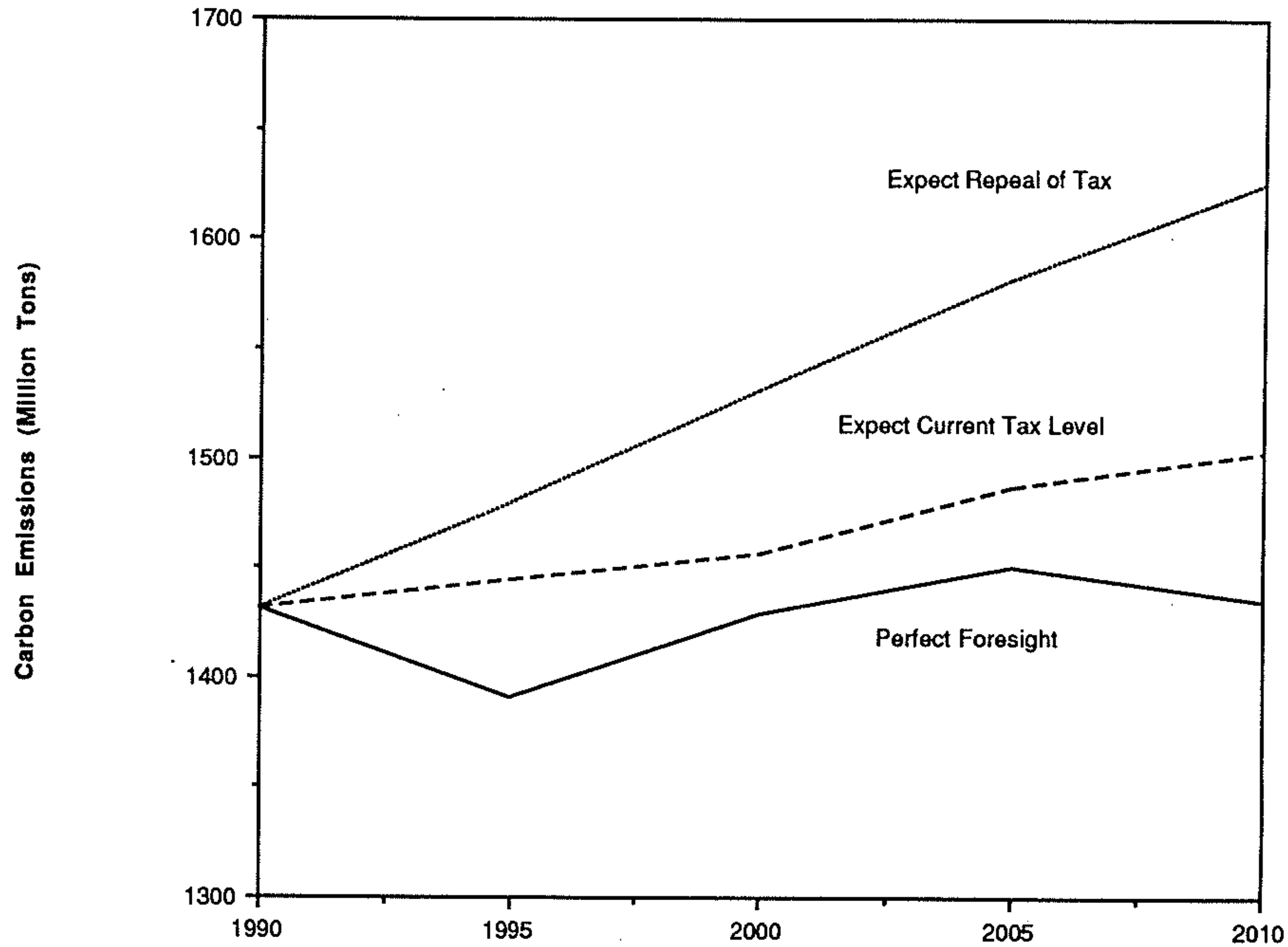


Figure 5



Carbon Emissions (Million Tons)
1700
1600
1500
1400
1300
1990
1995
2000
2005
2010
Expect Repeal of Tax
Expect Current Tax Level
Perfect Foresight

suboptimal relative to this assumption, and this is an important cause for the higher level of taxes predicted by TGAS. Because consumers do not have perfect foresight and uncertainty about future prices reduces their willingness to invest in capital that would optimize profits or utility, the higher level of taxes forecast by TGAS probably are more consistent with the signal that would be needed to achieve a given level of emission reduction.

Capital Malleability

Capital malleability refers to the ease with which capital's labor and energy requirements can be changed. The potential for change is affected greatly by the way in which the model represents capital stock. General equilibrium, technology choice, and econometric models differ in the way in which they represent capital and these differences are correlated with the level of tax needed to achieve a given level of emission reduction.

The "putty-clay" nature of capital determines the ease with which capital's energy and labor requirements can be changed. Capital of current year's vintage can be viewed as "putty." When firms choose among technologies, they pick from a wide variety of energy-using capital. This equipment varies in cost and energy requirements. Consistent with the notion of a production isoquant, energy efficient capital tends to be more expensive. The variety of choices and the trade-off between the cost of capital and its energy efficiency allows firms to adjust new investments to the current (and expected) price of energy. Once the capital is purchased however, the "putty" turns to "clay." That is, the amount of energy required to produce a unit of output by a specific type of capital is relatively fixed, regardless of current or expected prices. This rigidity implies that energy consumption (and carbon emissions) cannot adjust completely to a change in current or expected prices until the capital stock is changed. Because capital stock is replaced only slowly, complete adjustment to a carbon tax requires a relatively long period.

Models differ greatly in the way that they represent the "putty-clay" nature of capital. In general, GE and technology choice models represent the loss of flexibility most accurately. They do so by tracking the age of capital, which is termed "vintage." The energy requirements of new capital is determined by the existing price environment. Technology choice models simulate the purchase of specific technologies (e.g. electric arc furnaces) whose energy requirements are determined by engineering studies of current specifications and potential improvements. GE models simulate the purchase of technologies that maximize the net present value of profit (or utility) given current and expected prices. Once these decisions are made and new investments are installed, the energy requirements for capital of this vintage is held relatively constant as the stock ages.

Some GE models do not track the vintage of capital stock, such as DGEM and CETA. Without a explicit representation of vintage, agents can adjust the entire capital stock in a way that allows it to maximize the net present value of utility or profits given that year's current and expected price of energy. This allows the model to reduce greatly, the carbon tax that is needed to achieve a given level of emission reduction. The effect of a malleable capital stock and a priori assumptions about consumer behavior on the tax can be illustrated as follows. Suppose policy makers impose a tax of $100 per ton. This tax would increase the price of a barrel of crude oil to $33 if the pre-tax price were $20. The technology that maximizes the net present value of profit when oil prices are $20 a barrel is very different from the technology that maximizes the net present value of profit when oil prices are $33 a barrel. Models that do not vintage capital allow firms to change instantly their existing stock of capital from the type that maximizes the net present value of profits when oil prices are $20 a barrel to the type that maximizes the net present value of profits when oil price are $33 a barrel. This overstates the reduction in emissions that can be achieved in the short run because a long period is required to replace the capital stock that was purchased and installed when oil prices were $20 with the technology that maximizes profit or utility when oil is $33.

On the other hand, econometric models tend to forecast a relatively high tax because they do not represent capital stock explicitly. Econometric models of energy demand generally are estimated from time series. These time series represent changes in energy demand that are associated with yearly rates of replacement and relatively small retrofits of existing capital. These changes represent only a small fraction of the change in energy use that is possible when the entire capital stock is replaced with technologies consistent with that year's price environment. As a result, econometric models tend to underestimate the reduction in energy use and carbon emissions that results from a complete adjustment to a rise in energy prices that is generated by a carbon tax.

The effect of capital malleability on the tax required to achieve a given level of emission reduction is best illustrated by the forecast for carbon emission by electric utilities that is forecast by TGAS and DGEM. TGAS was unable to estimate econometric equations to model the mix of fuels used by utilities to generate electricity because government regulation and the long life of capital stock delay adjustments to changes in energy prices. Instead, TGAS assumes that new capacity is the same mix and efficiency of generation capacity as the most recent observation. This makes coal the predominant source of new capacity and insulates decisions regarding fuel use by this sector from the effects of a carbon tax. This tends to increase the tax needed achieve a given level of emission reduction because raising the price (and demand) of electricity via the fuels used to generate electricity is the only way that a carbon tax will reduce emission from coal-fired electricity plants. Conversely, GE models that do not vintage capital allow the existing stock of electricity generating capacity to change the fuel used to fire its boilers. This allows for a dramatic reduction in carbon emissions because most (86 percent in 1990) of the coal consumed in the US is burned by electric utilities. For example, DGEM forecast that a $100 carbon tax reduces coal fired capacity, which accounted for 55 percent of net generation in 1990, by more than 70 percent in 2000 relative to the base case (CBO, 1990). This reduction is possible due to lower demand for electricity and a 71 percent increase in non-fossil energy (mostly electricity generated from nuclear and hydro).

Assumptions about the malleability of capital affects the reliability of tax forecasts that are generated by models of different types over time time horizons. In the short run, models that do not vintage capital stock clearly overstate the ability of a carbon tax to reduce emissions. In the long run, econometric models that do not represent capital stock understate the ability of a carbon tax to reduce emissions. These differences imply that taxes forecast by econometric models such as TGAS are reliable up to 15-20 year forecast horizon whereas the tax forecast by GE models that do not vintage capital are reliable for a forecast horizon of 15 years or longer. To some degree, econometric models recognize this limitation. Although TGAS and IEA could be run to the year 2100, their operators have not done so. On the other hand, operators of DGEM and CETA report taxes and emissions for a short forecast horizon (1995, 2000). These results cannot be used to guide policy and expand greatly the range of carbon taxes needed to achieve a given level of emission reduction.

CONCLUSION

Much of the difference among models regrading the size of a carbon tax needed to achieve a given level of emission reduction is associated with the level of aggregation and a priori assumptions about consumer behavior and capital malleability. Once these effects have been identified, the policy maker must choose among models to set a tax consistent with the level of emission reduction chosen by society. I believe that econometric models such as TGAS and IEA have characteristics that make their forecasts more reliable for setting taxes in the short run. By simulating energy user prices, these models are able to model more accurately, the change in absolute and relative prices experienced by consumers. By relaxing assumptions about perfect foresight and intertemporal optimization by consumers, they simulate more accurately, consumers' willingness to act on current and anticipated changes in end-user prices (5-15 years). Finally, by representing the structural rigidities, they represent more accurately, the time required to replace capital and change the energy required to accomplish specific tasks.

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FIGURE CAPTIONS

Figure 1 The end-user price of various fuels in France (widely spaces diagonal stripes), Germany (horizontal stripes), Italy (narrowly spaced diagonal stripes), Japan (shaded), UK (Dark diagonal stripes) and the US (filled).

Figure 2. The ratio of end-user to first pruchase price of refined petroleum products and natural gas in France (widely spaces diagonal stripes), Germany (horizontal stripes), Italy (narrowly spaced diagonal stripes), Japan (shaded), UK (Dark diagonal stripes) and the US (filled).

Figure 3. Historical simulation of US energy demand by TGAS (solid line) and a forecast by TGAS holding the differences the annualized rate of expected real oil price increases and real interest rates(dotted line).

Figure 4 Difference between annual rate of appreciation and real interest rates over one year (open squares), two years (closed diamonds), three years (closed squares), four years (open diamonds), five years (closed squares), six years (open squares), seven years (closed triangles), and eight years (open trianlges).

Figure 5. Emission of carbon with tax that stabilizes emission under various assumptions regarding consumer foresight in which consumers form their expectation of energy prices based on perfect anticipation of the increase in carbon taxes (solid line), based on the assumption that carbon taxes will remain at their current level (dashed line), and the assumption that carbon taxes will be removed (dotted line).

NOTES

1. I refer to GLOBAL 2100 in many parts of this paper. These citations are not meant as criticisms of GLOBAL 2100. Rather, I refer to GLOBAL 2100 most often because Manne and Richels have documented their model more thoroughly than most.

2. Exceptions to this categorization exist. For example, DGEM is a national model of the US, but forecasts a very small carbon tax. The cause(s) for its small tax is given in the section on a priori assumptions.

3. The definition for the final consumption of energy is different from the definition for the final consumption of goods and services that is used in national accounts. Final consumption of energy denotes the point at which the potential energy of an energy is converted irreversibly (in a thermodynamic sense) to kinetic energy.

4. The IEA model is a notable exception. The similarity between forecasts generated by TGAS and IEA is noted.

5. The optimum amount of energy consumption is determined by the intersection of the budget line and the production isoquant or iso-utility curve. A carbon tax changes the optimum level of energy consumption by changing the slope of the energy budget line, which reflects the percentage change in the price of energy.

6. A $360 carbon tax causes a 130 percent increase in the first purchase price of oil.