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Restraining carbon emissions: measuring energy use and efficiency in the USA

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In this paper, we discuss the difficulties in measuring the effectiveness of policies intended to encourage compliance with international carbon restraint agreements. We establish the connection between energy consumption and carbon emissions, and demonstrate a method of disaggregating changes in each into changes in economic activity and structure, energy intensity and fuel mix factors. We utilize this method to analyze the historical trends in energy consumption and carbon emissions in the USA from 1960 to 1993. We analyze the contributions of the various factors to the restraint or encouragement of energy use and carbon emissions. We conclude that, in general, changes in the levels of economic activity have tended, all other factors being equal, to increase emissions, whereas declines in energy intensity and shifts in fuel mix have tended to restrain emissions. Changes in economic structure have had mixed effects. Finally, we discuss the problems with the available data which make the observation of the impact of energy and carbon policies difficult. © 1997 Published by Elsevier Science Ltd.

Keywords: Carbon emissions; Energy policy; Factorial decomposition

The reasons for concern about energy have changed since the 1973 oil crisis awakened scientists, policy makers and citizens alike. Worries in the 1970s about oil security and 'running out' of fossil fuels have shifted to a consideration of the environmental impacts of producing and using energy, most recently the effects of carbon (primarily in the form of carbon dioxide or CO_2) and other so-called 'greenhouse gases' released into the atmosphere from the burning of fossil fuels.[1] This change has had important consequences for energy and environmental policies. Following the June 1992 United Nations Conference on Environment and Development (the 'Earth Summit'), governments of virtually all industrialized countries proposed objectives for restraint in greenhouse gas emissions; the goals of the USA are reflected in the *Climate Change Action Plan* (Clinton and Gore, 1993) and the *Climate Action Report* (United States Department of State, 1994).

In this paper, we argue that the consideration of trends in total greenhouse gases or, more specifically, carbon emissions alone is insufficient for policy makers seeking to develop effective carbon restraint policy. We describe a method of disaggregating factors underlying energy consumption and carbon emissions. We then utilize this method to analyze the energy consumption trends underlying the changes in carbon emissions in the USA. We review the record of USA energy consumption for the period 1960 to 1993 by economic sector and fuel type, and quantify the associated carbon emissions. We show that greater energy use resulting from increased activity in the form of more travel and freight shipments, more output from industry, increased commercial services and more households and household equipment would have boosted carbon emissions by about 25%, all other factors being equal. At the same time, more efficient energy use alone would have reduced carbon emissions by 20%, and changes in the overall fuel mix would also have reduced emissions. The net result was almost no increase in carbon emissions between 1973 and 1989, the last full year of economic growth before the recession of the early 1990s. In the last few years, economic recovery has again pushed

[1]In this paper, we quantify carbon emissions on the basis of the total carbon contained in combusted fossil fuels. We ignore the small differences in the efficiency of conversion among fuels and processes from fuel-based hydrocarbons to atmospheric carbon forms. Moreover, we ignore both the production of other greenhouse gases which often occurs when fossil fuels are burned and the emissions of unburned methane. Our method is primarily applicable only to carbon because of its relationship to energy consumption.

up energy consumption and carbon emissions. Currently this upward pressure is considerably greater than the restraining influences of more efficient energy use and the slow shift to a less carbon-intensive fuel mix. In this work, we have not explicitly addressed the role of energy prices in influencing demand because of limitations in our model, although we were able to reach some preliminary conclusions in our earlier research on USA manufacturing energy consumption (see Golove and Schipper, 1996). We hope to correct this deficiency in our future research.

International concern: restraining carbon emissions

The United Nations Framework Convention on Climate Change (Framework Convention) (United Nations, 1992) aims to restrain emissions of carbon dioxide and other greenhouse gases. The Annex I countries[2] intend to reduce carbon emissions by a certain percentage (eg Denmark) or to a certain base-year level (eg USA, Germany), or to restrain their growth to a certain specified level (eg Spain). Policy makers striving to meet these goals and observers following the progress towards them are asking about the efficacy of proposed and adopted policies, how well these 'targets' are being approached and the likelihood of achievement. Rather than focusing solely on the trends in total annual emissions, however, we believe that meaningful answers require the explanation of trends in emission levels by reference to changes in economic activity and structure, energy efficiency and fuel mix. The approach taken in this paper is to relate the changes in the structure and intensity of energy use to changes in carbon emissions. Whether the targets provided by the Framework Convention or subsequent agreements are adequate is not the issue here, but rather whether we can measure the success of the approach to achieve the specified goals in a manner which provides an insight into the reasons for such success (or failure).

Methodology

The greenhouse gas emission goals from the Framework Convention are described in terms of total emissions per year. Yet, indicators of total emissions do not tell the whole story of carbon (a key component of carbon dioxide, perhaps the most important greenhouse gas) restraint initiative success, because these indicators cannot resolve the particular components of energy use and carbon emission which may have been subjected to specific policy interventions.

We propose to utilize a method of factorial decomposition which has been employed successfully in previous studies to analyze changes in energy consumption patterns in order to assess changes in energy consumption and carbon emission patterns. Changes in energy use were analyzed for the USA (Schipper *et al*, 1990a; Golove and Schipper, 1996), Norway (Schipper *et al*, 1990b), Denmark (Schipper *et al*, 1993) and Sweden (Schipper and Price, 1994).

When we add the carbon dimension to our analysis, the situation is made more complicated. For example, certain possible carbon restraint policies may have effects which are obscured either by unintended consequences of the policies or by trends independent of the policies in question. For instance, one policy may be aimed at restraining emissions from space heating in housing by stimulating increases in the level of thermal insulation. However, since increased house area heated, in itself, tends to increase carbon emissions, we must also be mindful of how the house area itself is changing, as well as whether the effect of increased house area heated offsets the gains from increased energy efficiency.

If the Framework Convention commitments are to be meaningful, each signatory needs to make a full account of its greenhouse gas emissions. To our mind, this means accounting for components of change, not simply adding up sources (and sinks) of these gases. The spirit of the Framework Convention suggests that carbon emission restraints should be accomplished regardless of trends in economic growth. Achieving given emission levels because of economic recession, for example, although reflecting the letter of the treaty, violates the spirit of the agreement. This point becomes particularly salient in the light of a report that the ability of Germany and Belgium to meet their Framework Convention commitments 'is due to the severity of the recent economic recessions rather than the result of their efforts to reduce their carbon emissions' (DRI/McGraw Hill, 1995). In addition, without understanding the components of change, it may be impossible to target policies to specific sectors where emissions will occur.

Political leaders must be able to assess quickly the effectiveness of their efforts to restrain carbon emissions. However, we must ask whether the present data sources and modes of analysis are sufficient to provide such information on a timely basis. We must also ask whether the accuracy of the data is sufficient to observe the impacts of policies. If policy proposals have effects on the order of a couple of per cent or less, the impacts may be lost in the margin of error in the statistics. At the same time, because of the numerous interactive factors affecting energy consumption, predictions of the impacts of individual policies are highly uncertain.

Decomposition of changes in energy use and carbon emissions

Energy consumption and subsequent carbon emissions are driven by activity levels, sectoral structures, energy intensities, fuel mix and utility effects. Carbon emissions can be understood as resulting from a given level of energy consumption times a factor representing the carbon content of the fuel mix. Energy consumption is measured in at least two different ways. Final energy consumption refers to the total amount of energy converted from fuels or electricity to other forms, ie heat, available for a given purpose, although the

[2]Annex I countries are those industrialized nations that have agreed to certain specific carbon restraint provisions of the Framework Convention.

output or activity may not be specified. Final energy consumption is also called 'delivered' or 'site' energy. Final consumption is usually recorded by the final demand sector (eg residential, transportation) and sometimes by end use (eg heating, trucking). Primary energy consumption includes the losses in producing, converting and distributing fuels and electricity to ultimate consumers and is the more relevant measure for calculating carbon emissions. For this study, we include only the losses that arise in the generation of electricity, these being far higher per unit of final energy consumed in a sector than losses for other forms of energy.[3]

Activity levels

Activity represents the gross measure of output in each sector. In the residential sector, population is used to measure activity, whereas passenger-km/year and tonnes-km/year are used in the travel and freight sectors. Either value added or subsector-specific measurements, such as tonnes of product manufactured, can be used for the manufacturing subsector. We use value added in this report because we need to aggregate output across subsectors; such aggregation is not possible using physical units.

The structure of energy use

The structure of energy consumption refers to the mix of activities for which energy is consumed. A structural measure for residential energy consumption is the floor area of all homes heated, whereas a structural measure for transportation is the percentage for a given year or the period of total passenger miles represented (separately) by automobiles, buses and other modes. Structure changes over the long term (eg new factories produce new products, or different lifestyles cherish different objects), as well as over the short term (eg a shift in production between existing products, or a shift in the modal share of transportation).

The intensity of energy use

Energy intensity is the ratio of energy consumed to output, activity or energy service. For example, the ratio of the amount of space heating energy consumed to the floor space heated is a measure of the energy intensity. Although energy intensity is related to the inverse of the energy efficiency, energy intensity is an observed term, usually averaged over a stock, whereas energy efficiency is usually only measured for a limited sample or a single device.

When we speak of energy efficiency, we recognize that there are at least two contexts: economic and technical. 'Energy efficiency', although not a formal economic concept, is used to refer to the lowest achievable cost-effective level of energy consumption for a given level of economic output. Improving efficiency in this context means lowering the overall costs for a given level of output or consumption by improving the energy efficiency in a technical sense. 'Energy efficiency' in a technical sense means the ratio of goods or services produced to energy inputs. Improving energy efficiency, in this context, means increasing the ratio, either by increasing the output while holding energy inputs constant, or by holding output constant while decreasing the energy input. Obviously these two definitions are not the same, but they may be applied at the same time. To avoid confusion, we reserve the term 'energy efficiency' for use as a technical term, devoid of economic context.

Fuel mix and utility mix effects

Fuel mix refers to the mix of fuels used directly in the consumption of final energy and, indirectly, from the perspective of the energy end user, in the production of electricity. This measure is particularly significant in the calculation of carbon emissions, since different fuels may have very different 'carbon intensities' or ratios of carbon to energy content. Carbon intensities vary within a specific fuel type, such as between batches of coal, but the variation is particularly large between fuels. The impact of the variation within a single fuel type is generally overcome analytically by the use of average carbon intensities or 'emissions factors'. Because of the different carbon intensities, total carbon emissions per unit of economic output may change, independent of shifts in the structure of energy intensity. In terms of compliance with the Framework Convention, one of the key adjustments being made in the USA is the switch from coal to natural gas as the fuel of choice for electricity generation.

The utility mix effect captures those changes in carbon emissions occurring due to changes in the efficiency of electricity generation and in the mix of fuels used to generate electricity. We distinguish between fuel mix and utility effects because the former is undertaken by energy users and the latter by utilities. Each group sees different energy prices, different regulatory forces and different policy incentives.

Findings: USA energy use and carbon emissions

In this section, we use a method of factorial decomposition based on Laspeyres indices to measure the components of change in USA energy use and carbon emissions relative to 1973. We have chosen 1973 as our base-year because of the significant economic and energy use impacts brought about by the oil crisis of that year. These indices permit us to examine the effect on sectoral or total energy use and carbon

[3]This is justified because the 'upstream' losses of primary energy used to generate electricity, typically twice the value of the electricity actually delivered to each end use, are so much larger than the upstream losses associated with providing liquid, gaseous and solid fuels, which are typically 5% to 15% of the fuel actually delivered. In the aggregate as well, electric utility sector losses are considerably greater than other energy sector losses. Moreover, the substitution of electricity for fuels for heating leads to a reduction in final energy use, but in most cases an increase in primary energy use and possibly carbon emissions. By including the upstream losses, we also capture the carbon emissions in those losses. Although the addition of this burden to electricity is resisted in some analyses, its omission can imply that switching from fuel to electricity is a viable method of reducing emission liabilities. However, omitted emissions are still emissions. For more exacting work, such as estimating the carbon content of various alternative transportation fuels, full fuel cycle analysis is very important.

emissions of real changes in one component (activity, structure, intensity, fuel mix or utility effect) when the others are held constant at the base-year values. In other words, we examine 'what if' scenarios over various time periods in which one component reflects the actual values for each year, and the others are held constant at 1973 levels over the same period. Although the factors we identify are not completely independent of one another, the factorialization provides insights into which components in each sector account for upward or downward pressures on energy use and carbon emissions.

Sectoral findings: residential

Figure 1 shows that the activity (population) in the residential sector has tended to increase energy use slowly since 1960. In addition, the structure of the sector has shifted towards more energy-intensive activity per capita. For example, there has been a move to larger floor space and more appliances per capita. Indeed, there is also more housing per capita. Actual energy consumption has remained relatively flat since 1973 despite these increases, because of declining energy intensities in this sector. These declines were led by significant drops in the ratio of energy use for heating to area heated and reductions in the electricity used in new appliances (and for washing equipment, in the electricity and gas used even in existing appliances). Overall, actual household energy use is not growing as rapidly as incomes, as the ownership and use of major devices appears to be reaching saturation. On the other hand, energy intensity declined less rapidly in the early 1990s than in the 1980s.

Annual carbon emissions in the residential sector increased by less than 5% between 1973 and 1991, despite a shift in structure, which would have increased emissions by nearly 20%, and an increase in activity, which would have increased emissions by nearly 20%. The small decline was the result of a marked decrease in energy intensity during this period. For example, although there was increased ownership of electric appliances and a rise in the share of electric heat, these components of 'electrification' did not lead to a corresponding increase in electricity use because new appliances and new homes heated with electricity were considerably less electricity intensive than those already in the stock in 1973. Overall, the shift in residential fuel mix alone would have decreased emissions by only a few per cent. The decline in energy intensity alone would have reduced emissions by nearly 30% and a small decrease in emissions would also have occurred from the mix of fuels used by utilities. These two factors combined to limit the increase in total carbon emissions in spite of a 1.7% per annum increase in the number of households.

Sectoral findings: services

In this sector (Figure 2), actual consumption has increased only marginally since 1973, after a rapid increase in activity from 1960 to 1973. Activity, measured as the gross domestic product (GDP) in this sector, has increased significantly. Decreases in energy delivered intensity, both from more efficient use and from a modest shift to electricity for heating (instead of the direct combustion of fossil fuels), have mitigated the impact on total energy use of increased activity over the period since 1973. Primary energy intensity fell by considerably less because of the increased use of electricity. We cannot measure a structural effect from the available data. The services sector saw the largest change in activity in the period from 1960 to 1993, increasing by more than 60%.

The effect on emissions (Figure 7) was enhanced by a shift in fuel mix towards electricity which, alone, would have led to an increase of around 10%. Nonetheless, carbon emissions rose by only about 20% during this time. This can be explained by the 'utility effect' or a shift to lower emissions per unit of electricity, which by itself decreased emissions by about 10%, and to a large change in energy intensity which would have decreased emissions by 30% over this period.

Sectoral findings: passenger transport

Figure 3 shows modest increases in energy consumption in the travel sector since 1973. Prior to 1973, the growth in energy use in this sector was much greater. Declining intensities for automobile and air travel since 1973 mitigated the

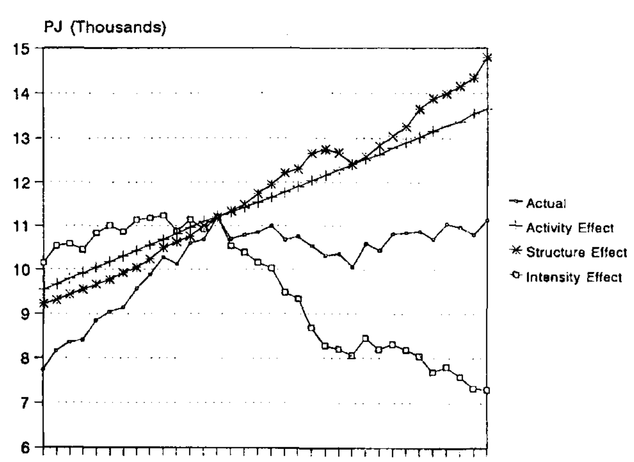

Figure 1 USA residential sector: impact of changing activity, structure and intensity on final energy use

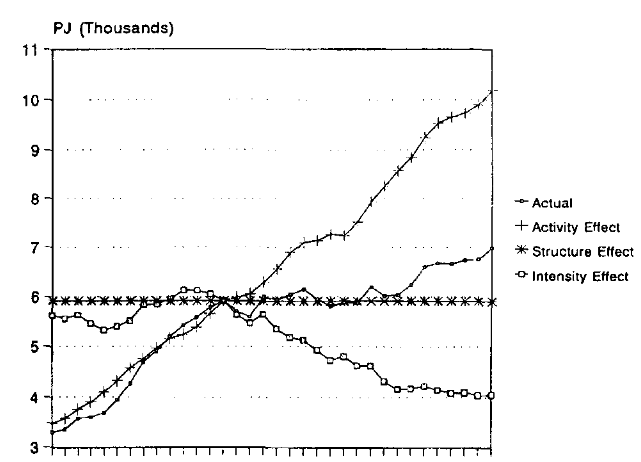

Figure 2 USA service sector: impact of changing activity, structure and intensity on final energy use

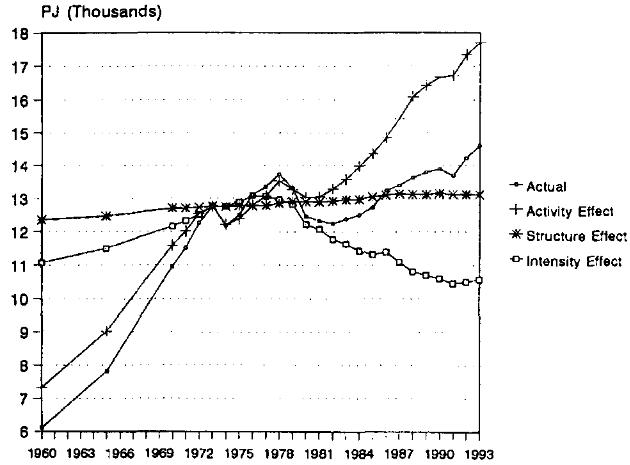

Figure 3 USA passenger transport sector: impact of changing activity, structure and intensity on final energy use

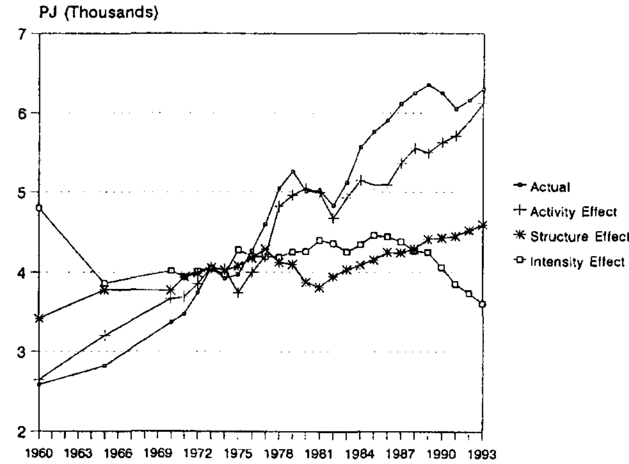

Figure 4 USA freight transport sector: impact of changing activity, structure and intensity on final energy use

continued increase in travel, driven in turn by a growing number of households and household vehicles, increased drivers' licenses and a greater use of air travel. Modal structure shifted continually towards automobiles in the 1960s, then towards air travel thereafter, boosting energy use slightly. After 1991, the intensity of automobile use (in fuel/km) or travel (in fuel/passenger-km) began to increase.

Carbon emissions from the passenger transport sector (Figure 7) increased by less than 10% between 1973 and 1991, although activity, measured in passenger-km (pkm), increased by almost 30%, and structural change (modal mix) alone would have increased emissions by approximately 3%. An approximate 20% decline in energy intensity (MJ/pkm), together with a small reduction from a shift in the fuel mix, combined to limit the increase in total carbon emissions. As in the residential and services sectors, actual increases in carbon emissions from the travel sector were held down by declines in energy intensity, despite a large increase in activity and a small shift in structure towards more emissions. It is noteworthy that the fuel intensity of automobile travel failed to decline in the period 1991 to 1993 for the first time since the mid-1970s.

Sectoral findings: freight transport

Figure 4 shows that actual energy consumption increased consistently between 1970 and 1991 in the freight sector, with a brief downturn from 1988 to 1990. Activity levels have generally increased,[4] while the structure has shifted slowly towards more energy-intensive truck travel. (Still, less than 35% of all freight is carried by trucks.) A decline in intensity in the last few years of the period appears to be responsible for a decrease in actual consumption.

Also in the freight sector (Figure 7), carbon emissions increased by more than 40% in the period between 1973 and 1991. Increased activity (tonne-km) alone would have increased emissions by slightly more than 30%, while structural change (modal mix) alone would have increased emissions by nearly 20%. A small decline in energy intensity (MJ/tonne-km) in this sector in recent years was not sufficient to overcome the large increases in activity and structural change towards more carbon-intensive activity. A recent trend towards decreasing emissions appears to have been reversed in 1992.

Sectoral findings: manufacturing

Energy consumption in the manufacturing sector, as shown in Figure 5, peaked in the early 1970s, although activity levels have increased throughout the period, with the exception of recessionary times. Structural changes have reduced energy consumption during the period by about 12% (even accounting for a slight upturn in output of energy-intensive branches of manufacturing after 1988). Final energy intensity has fallen by almost 40% between 1973 and 1993, and primary energy intensity by about 25%. In contrast with the changes in other sectors, intensities fell almost as rapidly in the 1960–1973 period.

Manufacturing (Figure 7) is the only sector that experienced

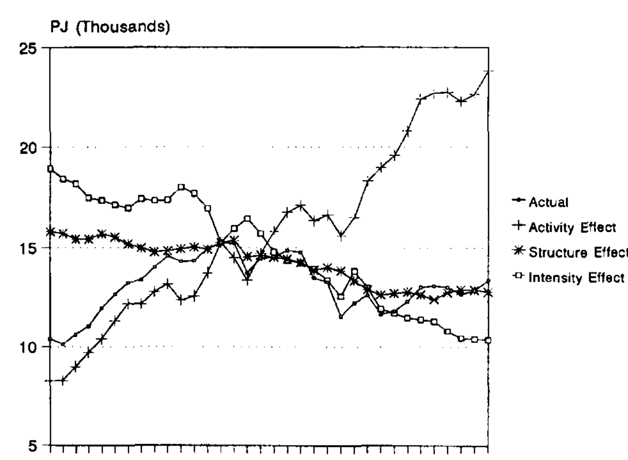

Figure 5 USA manufacturing sector: impact of changing activity, structure and intensity on final energy use

[4]The decline in freight activity evident in Figure 4 appears to have been a result of the recession.

a decline in total emissions between 1973 and 1991, despite a 50% increase in activity over the period. Both the fuel mix and utility effects led to small decreases in emissions, while the shift in structure led to an approximately 15% decrease and the decline in energy intensity led to more than a 30% decrease in annual carbon emissions over the period.

Aggregate energy use and carbon emissions

Figure 6 shows the final energy use by sector in the USA economy from 1970 to 1993. This figure displays energy consumption in the residential, services (commercial), travel, freight and manufacturing sectors. Energy use values in the manufacturing sector for the period 1992–1993 are estimates because of a lack of available data. Roughly 15% of the total USA final energy use comprising the agriculture, mining, construction and energy sectors (electric and gas utilities and petroleum refining) and about 20% of transportation energy consumption (natural gas used in pipelines, bunkering of international shipping and some miscellaneous uses of fuels for vehicles and private boats) are not shown because of a lack of available data allowing us to associate such energy consumption with well-defined activities or outputs.

Between 1960 and 1973, intensity changes in the five sectors increased primary energy use by an average of 0.3%/year, although decreasing final energy use by 0.4%/year. The difference in these two results arises from the increased use of electricity in the economy. However, between 1973 and 1993, intensity changes reduced primary energy use by 1.3%/year on average and final energy use by 1.7%/year. The activity effect for the period 1960 to 1973 increased final and primary consumption by 3.5%/year. Changes in activity during the 1973 to 1993 period raised both final and primary energy use by 1.8%/year. Structural change during the earlier period increased both final and primary energy use by 0.5% and 0.6%/year falling to 0.1% and 0.2%/year respectively during the latter period. Changes in the structure and activity in each sector together raised primary energy use by 8.8%/year and final energy use by 8.2%/year between 1960 and 1973. This same combination of effects only raised primary energy use by 2.0%/year (1.9%/year for final energy) between 1973 and 1991.

Figure 7 and Figure 8 show the USA carbon emissions by sector from 1970 to 1993. Manufacturing makes the largest sectoral contribution to carbon emissions as of 1993, representing nearly 300 Mtonnes of carbon. The residential and travel sectors emit comparable levels, while the contributions of the services (approximately 200 Mtonnes C) and freight (approximately 100 Mtonnes C) sectors are smaller. Carbon emissions from the USA residential sector by end use are dominated by space heating and appliances, which together account for nearly three-quarters of the total sectoral emissions. Electricity use in the USA services sector accounts for more than two-thirds of the total sectoral carbon emissions. As would be expected, automobile and light truck use account

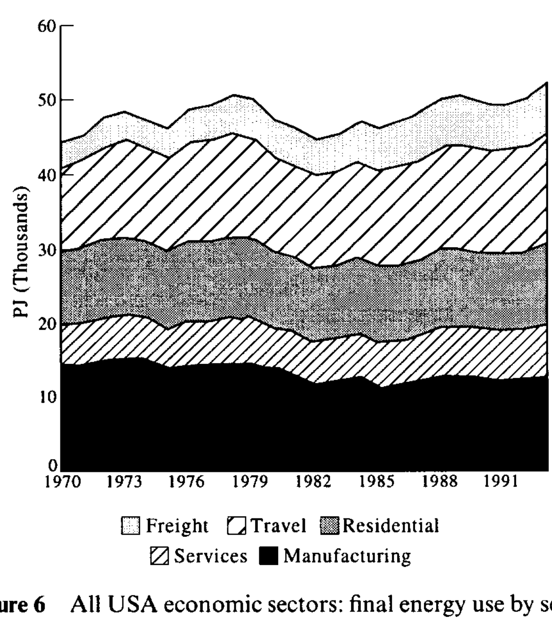

Figure 6 All USA economic sectors: final energy use by sector

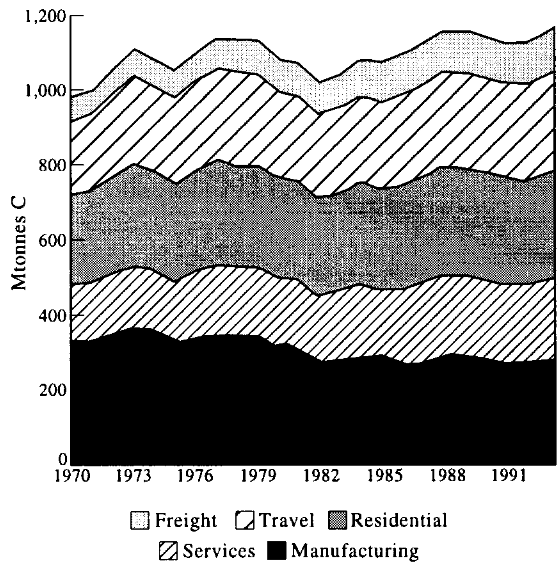

Figure 7 USA carbon emissions by sector

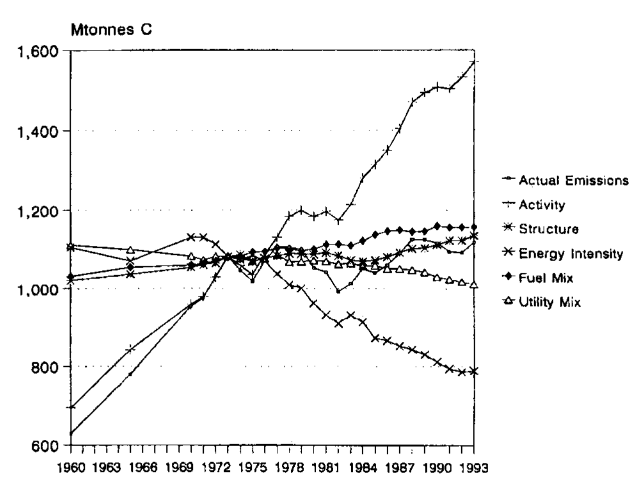

Figure 8 All USA economic sectors: impact of changing activity, structure and intensity on carbon emissions

for more than 80% of the total travel-related carbon emissions. In the freight sector, truck transport also represents more than 80% of the total sectoral carbon emissions. Within the manufacturing sector, it is particularly interesting to note the decline in carbon emissions from a high of nearly 350 Mtonnes C in the early 1970s to a current level on the order of 300 Mtonnes. Of this total, the chemical and ferrous metal subsectors together comprise more than half of the carbon emissions.

Figure 9 summarizes the results of our carbon decomposition in a somewhat different way. We show the contribution of each sector to the effect on emissions in 1991 for each factor affecting those emissions. We compare actual 1973 and 1991 emissions by sector, and show the activity, structure, carbon intensity, energy intensity, fuel mix and utility effects.[5] Comparing each effect with actual 1973 emission shows that, by 1991, activity had boosted emissions significantly and structure and fuel mix had boosted emissions slightly, while the utility effect had reduced emissions slightly and the intensity effect had reduced emissions significantly. The carbon intensity of the economy decreased significantly.

Figure 9 also shows that the 'fuel mix effect' was significant in the manufacturing sector, but unimportant elsewhere. The utility effect measures the impact of the higher share of electricity in each sector and, as such, had almost no impact on travel or freight, two sectors with little electricity use. The intensity effect, by contrast, struck almost equally at all five sectors shown. It is worth noting that the period before 1973 was marked by a strong rise in actual emissions. This was driven, in turn, by the activity and structural factors, as well as fuel mix, as increased electricity use raised emissions more than the slow decline in oil and coal use in manufacturing, services and households (in favor of natural gas) reduced emissions. The energy intensity effect increased emissions during this early period, led by increases in households, services and travel, offset only partially by the falling carbon intensity of manufacturing and freight.

At the level of the entire economy, activity level changes boosted energy use significantly. However, structural changes between 1973 and 1991 offset each other since the 'structure' column reaches to about 63 EJ, within 5% of the 1973 primary energy value. Energy intensity changes reduced energy use to offset most, but not all, of the effects of increased activity. We found that, during the period 1973 to 1991, GDP increased at a rate of 2.3%/year, down from an average growth rate of 3.9%/year from 1960 to 1973. The decline in the ratio of energy consumption to GDP averaged 2.2%/year for final energy and 1.7%/year for primary energy. These aggregate results differ from those obtained from measuring the energy intensities directly.

Why do these two indicators give apparently different results? The reason is that the growth rate of GDP is higher than the growth rate of the impact of changes in both activity and structure on energy use, an effect that we can call 'energy services'. This can be understood as the effect of holding all energy intensities in the economy unchanged, but letting sectoral activities and the structure of each sector change. The difference between the rate of growth of GDP and the rate of growth of energy services itself acts to drive down the rate of energy use to GDP. This difference is important for our measurement problem, because it indicates that there is a potentially significant source of downward pressure on the ratio of energy use to GDP, and therefore the ratio of carbon emissions to GDP, all other factors being equal. Many would welcome a reduction in the ratio of emissions to GDP for any reason. However, it would be unfair to attribute this part of the reduction to the *Climate Change Action Plan* or other policies that were aimed specifically at energy use.

For the economy as a whole, increased activity alone (population, value added in manufacturing and services, total travel and total domestic freight) would have led to approximately 50% higher levels of annual carbon emissions. Structural changes would have led to slightly higher levels of emissions. The combined effects of activity and structural changes would have increased emissions significantly, although this relative increase was still less than the increase in overall GDP. In other words, the overall impact of changes in the structure and levels of activity still left the economy with a declining ratio of emissions to GDP. Indeed, actual emissions from the specific sectors evaluated in this study showed only a negligible increase over the period studied. The impact on emissions of changes in activity and structure was offset primarily by a large decline in energy intensity in each sector. The impacts of shifts in fuel mix or utility mix were small over this period.

Structural changes had an uneven effect throughout the economy. A significant increase in emissions from changes in the residential sector (more equipment and area per capita) and modest increases from changes in travel (a larger share

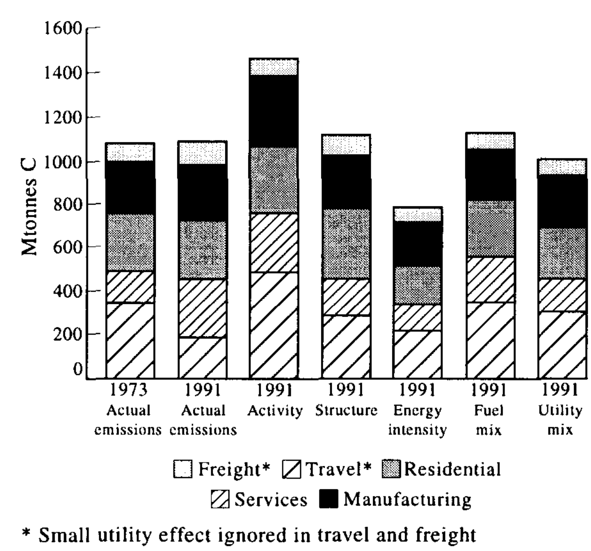

Figure 9 All USA economic sectors: impact of changes in structure, activity and intensity on carbon emissions, 1973 vs. 1991

[5]We use primary rather than final energy use in this comparison because it is more closely related to carbon emissions, since the losses incurred in the generation and transmission of electricity are included.

of air travel) and freight (a larger share of truck freight) caused increases in energy use that were offset through 1988 by decreases from manufacturing. After 1989, however, some of the manufacturing decrease was reversed, contributing to a small increase in the structural effect for the USA economy.

Summary: changes in USA energy use and carbon emissions between 1960–1993

We found that there has been a slight slow down in the decline of energy intensities since 1985. The decline between 1985 and 1991 matched that in the 1973–1979 period, but fell short of the rate of change during the intervening 6 years. That the slow down is more marked for final than for primary energy suggests that the rate of change of fuel intensities (industry, space heating, automobiles) is greater than the rate of change of electricity intensities (appliances). We also found that a decline in activity (in this case, recession) led to a slight decline in actual energy consumption in 1990 and 1991.

Finally, we found that the structural factor began to have an upward effect on overall energy use in 1989, offsetting some of the activity decline that appeared with the ensuing recession. One reason why the structural factor for the overall economy rose in the late 1980s was that the composition of output in USA manufacturing shifted slightly towards a more energy-intensive mix between 1985 and 1991. That this increase occurred during a period of falling energy prices suggests (but does not prove) that some of the shift away from energy-intensive production observed in the late 1970s and early 1980s was driven by higher energy prices. However, the ratio of cement or steel produced to total manufacturing output, whether the former is measured in value added or in tonnes, is clearly downwards, suggesting that most of the shift away from energy-intensive materials will persist on a long-term basis.

We believe that the carbon intensity of activities in the USA economy will continue downwards for the immediate future. However, the decline in energy intensities between 1985 and 1993 was only 1.4%/year compared with 1.7%/year between 1979 and 1985. This may seem like only a small reduction in the rate of improvement of energy efficiencies, yet the small change is combined with economic growth, which surged from late 1992 to the present. Moreover, we see from Figure 8 that actual emissions were on their way up before the last recession, and emissions appear to have climbed in the aggregate in 1992 and 1993. Although the data do not permit a decomposition yet, it appears that rising activity and the recent structural changes are likely to increase emissions, while falling intensities and an increase in the share of natural gas in power generation are likely to reduce emissions. However, the factors increasing emissions are stronger. In other words, overall USA carbon emissions will increase, but the growth rate of carbon emissions will still fall behind the rate of GDP growth because of efficiency improvements and the combined effects of activity and structural change. The recent trends in emissions that emerge from this analysis are foreboding. Apart from the drop in emissions caused by the recession of 1990–1991, activity and structure have been raising emissions, while the effect of lower intensities has weakened since the late 1980s.

Which sectors are quantitatively the most important to determining changes in energy use and resulting carbon emissions? This depends on how energy use is viewed. When looking at a single year, we see that automobile use alone accounts for some 13% of total USA emissions, while primary energy use for home heating is almost as important. Industry as a whole accounts for more than 30% of energy use, but represents a much more diverse set of processes than either automobiles or home heating. Within manufacturing, six major energy-intensive branches (refining, paper and pulp, chemicals, iron and steel, non-ferrous metals, cement) and food account for more than 70% of the total.

When looking at recent trends, the picture is somewhat different. Between 1973 and 1991, emissions from households have been nearly flat, and the number of households is now growing at less than 2%/year. There may be enough improvements in energy efficiency alone to limit emissions from this sector to close to present levels for the near future. Emissions from both freight and travel, however, are now increasing after decreasing for nearly two decades, in part because the fuel intensity of automobiles is no longer falling.

Total emissions from services have increased significantly, in spite of improvements in energy efficiency, because output has increased. Even discounting the recent recession, emissions from manufacturing continue to lag significantly behind output, as the importance of manufacturing continues to decline. By this measure, it would appear that services, travel and freight are the sectors where growth in emissions is potentially the strongest. Within these sectors, automobiles, trucks and electricity-using equipment represent the key end uses that should be scrutinized: can efficiency improvements in these areas be accelerated?

One way of determining where to focus measurement is according to where 'pledges' or 'goals' for improved energy efficiency have been set. Certainly the debate over the effects of the CAFE standards forced authorities to look more carefully at how fuel intensity and the use of light-duty vehicles varied. However, each of the policies or steps in the *Climate Change Action Plan*, by themselves, are generally too small to be resolved by the analysis presented here: none are as bold as the CAFE standard. The problem is not that the programs might not be successful, but that their full impact is still very small compared with the kinds of changes described in this report. Only when many years have passed can the effects of a program, if carefully monitored, accumulate to be seen above the noise and the ordinary or autonomous progress of more efficient energy use. Since energy intensities in manufacturing are falling anyway, it will be hard to assign a policy 'cause' to further changes. Programs affecting lighting or computers in the service sector show some promise for measurability, because the equipment in these sectors is replaced frequently.

From another perspective, however, it is the transportation sectors where growth in emissions is the most robust. There has been almost no move to alternative fuels or modes of travel offering significantly lower emissions per unit of travel or freight activity. The intensity of light-duty passenger travel is now rising and, indeed, the modal mix of travel continues to shift towards greater carbon intensity. For freight, the modal intensity of trucking is falling slowly, but the modal mix in freight continues to shift towards higher carbon intensity. Thus, these sectors have exhibited the most resistance to reductions in carbon emissions for many reasons which may be deeply rooted in the economic system and lifestyle choices. The service sector is a source of rising emissions, both from increased activity and from increased electrification, but there is considerable optimism that the efficiencies of electricity use in this sector can be improved to offset much of the growth.

Score keeping in the future: crediting change or forces behind change?

The foregoing analysis has had the benefit of hindsight. Twenty years of experience, surveys and innumerable studies have made the analysis of changes in energy use and carbon emissions relatively easy and have helped us to estimate the main causes of change. However, in the future, this will be more difficult, although energy data continue to improve. One reason is because policy makers want answers quickly, while budgetary pressures reduce the frequency of data publication. A more vexing problem is that the changes in energy efficiency or fuel mix in the future are likely to be more gradual than in the past, because energy prices are not likely to change as rapidly (or as radically) as occurred with the three major jumps in oil price, and the lack of perfect statistical independence among our variables will become more significant.

Theoretical models might help to isolate changes in energy use and energy efficiency. We could model the theoretical impact of new systems known (or tested) to be less energy intensive than those in the stock and compare expectations with actual results. Alternatively, we could use econometric estimation to see whether 'actual' energy use deviates from 'expected' energy use. The problem with the former is that our knowledge of how new systems really perform is not good enough to be able to discern the impact of their entry into the stock unless many years have passed or there is a truly large difference between new and existing efficiencies, the rate of turnover is large and we know accurately how much energy is used for the end use in question.

In principal, an econometric approach could 'predict' energy use in a way that could be compared with the actual use. The problem with this approach is that our historical basis for estimating how energy use should vary in the absence of policies, ie to compare with 'actual', is poor, even at the very aggregate level, unless we have access to surveys similar to those discussed here or many years have passed so that expected and observed changes are large. However, most policies are bottom-up, affecting individual components of energy use, something most econometric analyses cannot easily use. We believe that econometric analysis will complement the bottom-up approach, but cannot replace it. This is particularly true where there are concerns that improvements in energy efficiency might lead to measurable increases in the level of energy services demanded.

Conclusions

We have measured the changes in energy use and carbon emissions from most activities in the USA since either 1960 or 1970, depending on data availability. By decomposing the effects of changes in sectoral activity, structural change within sectors and changes in individual energy intensities, we found that, between 1973 and 1991, the growth in sectoral activities and structural changes, which boosted energy use by 1.9%/year, was almost offset by reduced energy intensities, which fell by an average of 1.3%/year. Since GDP grew by 2.3%/year, the ratio of energy use to GDP fell by a greater amount than caused by energy efficiency improvements alone. However, after 1985, the rate of improvement in energy efficiencies slowed, while the impacts of structural change increased the energy use somewhat. In all, USA energy use continues to grow less rapidly than GDP, but the gap in the 1990s in the growth rate is somewhat smaller than it was in the 1980s.

We applied the same analysis techniques to carbon emissions, and found an even greater gap between GDP growth and emissions. Structural changes and improved efficiency reduced the carbon emissions per unit of GDP, while, at the same time, the overall energy mix became less carbon intensive as utilities moved away from oil to natural gas and nuclear power, while still maintaining coal use. Greater activity and, to a lesser extent, structural changes continued to boost carbon emissions. Currently, this upward pressure is considerably greater than the retarding influences of more efficient energy use and a slow switch to a less carbon-intensive fuel mix. The importance of structural and activity changes underscores the need for a set of energy use accounts that relates energy use (and corresponding carbon emissions) to activities.

Current initiatives promise to restrain carbon emissions somewhat. However, these programs are generally small in scale compared with the changes in energy use we expect to occur due to changes in activity, structure, intensity and fuel mix. The results of current USA initiatives, even if fully implemented and successful, cannot be measured from present national data on energy use and activity. One serious problem is that we report energy use infrequently (every 3–5 years, with up to a 2-year delay in reporting results depending on the sector). This means we cannot begin to see changes in energy use, whether caused by our restraint policies or not, except after a time lag of sufficient length to allow results to accumulate above the general levels of uncertainty and to be captured by the infrequent surveys.

The USA, like most other industrialized nations, is discussing policies and measures to limit carbon emissions from energy consumption (and other sources), yet cannot accurately assess the impacts of those policies or separate such impacts from other effects which influence carbon emission levels. This inability is common to almost all economies, and will plague various negotiation processes over policies and measures as well as goals and targets. If there is to be meaningful carbon restraint, and serious policy measures to encourage that restraint, there must be better means of determining clearly the impacts of those measures on the energy uses giving rise to the emissions.

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