Recent Trends in the U.S. Energy Intensity: An Index Number Analysis[1]

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Introduction

The last 25 years have been a roller coaster ride for energy markets. World oil markets have taken dramatic swings, impacting oil production and consumption patterns. Domestically produced energy resources, natural gas and electricity, have experienced swings in price and consumption patterns in response to changes in technology, regulation, and other energy markets. In recent years, patterns of energy use continue to change. In 1997 and 1998, the economy grew at a rapid rate without a significant increase in energy consumption, even though prices declined. If the growth in the economy was largely in low-energy-using sectors, this decline in intensity could be attributed to a shift in economic activity rather than energy efficiency improvements.

For this paper, we use data from the Energy Information Administration (EIA),[2] the Bureau of Labor Statistics (BLS),[3] and Argonne National Laboratory (ANL) to examine recent trends in energy use, focusing on the relationship between nontransportation energy use and economic activity. We separately examine trends in aggregate, nontransportation electric and fossil fuel use relative to the gross domestic product (GDP). Specifically, we examine trends in the U.S. aggregate *energy/output ratio* or *energy intensity* of the U.S. economy (i.e., the ratio of nontransportation electricity consumption in kilowatt-hour [kWh] or fossil fuel consumption in Btu to GDP). We develop several indices to help explain the changes in these two measures of energy intensity; in particular, we adjust aggregate electric and fossil fuel intensity to account for shifts in the composition of US economic activity. We then examine whether these compositional changes, or *sectoral shift*s, in US economic activity explain the dramatic declines in the ratio of nontransportation energy use to GDP in 1997 and 1998, relative to recent history. The portion of energy intensity that is not explained by compositional changes is labeled *real energy intensity*.

In the late 1980s and 1990s, aggregate energy intensities in the nontransportation portions of the economy declined. This decline was larger and steadier for nonelectric energy than for electricity. Our analysis finds that, for both types of energy, sectoral shift played an important role in the decline. There was an increase in the role of sectoral shift (i.e., a more rapid decline) in 1997 and 1998. This increase in sectoral shift was augmented by a more rapid decline in real energy intensity relative to earlier years, resulting in the large observed drop in aggregate energy intensities.

There are a variety of potential explanations for this apparent change in the behavior of energy use relative to GDP. Rapid overall productivity due to new investment, energy efficient technology that is cost effective despite falling prices, short-term fluctuation in weather-sensitive energy loads, and changes in the mix of economic activities may all have contributed. We focus on measuring the economic mix, but also examine the possible role of the other factors, once we have accounted for the mix of underlying economic activity.

Historical Context

Previous studies have shown that some portion of the changes in aggregate energy intensity may be explained by the relative growth or decline in more energy-intensive or less energy-intensive activities (e.g., shifts from heavy manufacturing to high tech industries and services). When these shifts are accounted for, a clearer picture of the changes in the *efficiency* of the underlying energy-using activities is obtained. Studies of U.S. manufacturing over various years have found that as much as one-third of the decline in energy intensity was due to sectoral shift, with the remainder attributable to improvements in efficiency. Other studies of different countries, sectors, and years have found varying results. For some countries or years, shifts have had little empirical effect.[4] When examining aggregate energy intensity, it is important to account for the impact due to the composition of the underlying energy-using economic activity.

If we look at the very long picture of changing energy intensity (Figure 1), we see how energy use has evolved in the United States. Primary energy use per dollar of GDP (using 1992 chain-weighted dollars) was declining slightly before the energy price increases of the seventies, when the decline accelerated. In the late eighties, energy prices began falling and the decline moderated. For electricity consumption, the trend is quite different. Electricity intensity increased until the mid-seventies. At that time, the increase stopped and intensity declined slightly.

In this paper, we focus on two measures of energy intensity: electricity end use in kWh and nonelectric energy use in nontransportation sectors in Btu, but first we examine long-term trends for several other measures of energy use. Figure 1 shows the ratio of five types of energy use to GDP: (1) primary energy, (2) primary energy less electric end use, (3) nonelectric energy (i.e., primary energy less electric end use and losses), (4) nonelectric energy consumed in nontransportation sectors, and (5) electric end use. Energy prices are also shown in Figure 1.

All measures of energy intensity, except electric end use, show similar patterns after the late seventies but differ in the earlier years. Electric end use intensity follows a quite different pattern, rising at first, then declining only slightly; all other measures fall at various rates over the historical period. If we focus on measures 1-4, we can explain some of the difference in the trend lines. A more rapid decline in nonelectric energy than in primary energy less electric end use reflects the improved efficiency of electric conversion that occurred in the sixties and late seventies; there is little difference in the trend thereafter. Nonelectric energy consumed by nontransportation sectors is quite flat in the sixties and early seventies. This measure follows the general trend of the other measures, but declines more slowly in the eighties than the nonelectric energy intensity with transportation included, when corporate average fleet economy (CAFE) standards had an impact on the transportation component. All four measures of nonelectric energy intensity exhibit a similar, more rapid decline in 1997 and 1998 than in the early

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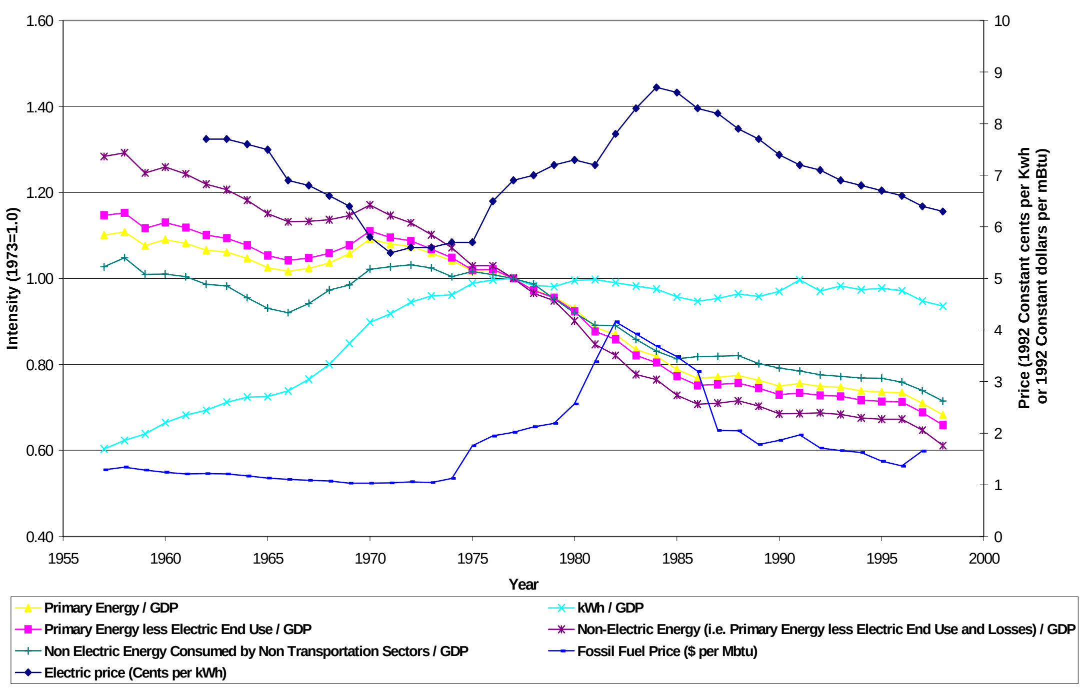
nineties. A much smaller decline in intensity is in evidence for electric end use intensity.

We focus on the recent trends in intensity for electric and nonelectric less transportation measures in more detail. Since we are effectively removing -transportation sector energy use from our analysis, we use BLS data to adjust GDP by removing commercial (for hire) transportation-related economic activity.[5]

Index Number Analysis of Recent Trends

This section presents a decomposition of the electric energy intensities and nonelectric, nontransportation energy intensities from 1983 to 1998. We compute an index of the contribution to energy intensity of the changing composition of economic activity. The remainder is treated as "real" intensity change. Identifiable trends in sectoral change and real intensity are examined. In particular, we look for any departure from recent history in 1997 and 1998.

Figure 1
Long-Term Trends in Energy Relative to GDP and Energy Prices



Electricity/GDP Trends: 1983-1998

The recent drop in electricity intensity occurred during a period of very rapid economic expansion. Using EIA data on electricity sales by sector and BLS data on economic activity, we compute an index of sectoral shift. To examine whether efficiency improvements or economic shifts among individual industrial sectors drove this decline in intensity requires a more detailed accounting of industrial activity than total industrial energy use. Using energy data from the LIEF model, together with BLS data, we disaggregated the industrial sector into 18 separate sectors.[6] A Divisia index of sectoral shift is computed from 1983-1998.[7]

Figure 2 shows the recent trends in electricity efficiency once we accounted for sectoral shifts. Aggregate electricity intensity from 1983-1998 is the same as it was in Figure 1 but is indexed to 1983 instead of 1973. The volatility in electricity/GDP ratio in the late eighties was driven by sectoral shift; specifically, production swings in primary aluminum, steel, and refining.[8] Sectoral shift accounted for about half of the overall –0.3% annual change in energy intensity during the period. Sectoral shift was more stable in the nineties, accounting for nearly all of the slightly higher -0.4% annual intensity change during that period. The average contribution of efficiency improvements remained nearly the same over the entire time period, except in the last three years. In 1995-1998, shift contributed about –0.3% to annual decline, the same as it did from 1990-1999. However, the average rate of real energy intensity change accelerated to –1.1%, compared with an overall rate of less than –0.2%.

Nonelectric Energy less Transportation/ GDP Trends: 1983-1998

A similar analysis was conducted for intensity of nonelectric energy use in the nontransportation sectors. The EIA data does not separate residential and commercial nonelectric energy. To overcome this limitation, a two-sector Divisia index is computed for 1983-1998.[9] The results of this analysis are shown in Figure 3.

The decline in the ratio of aggregate nonelectric energy use to GDP is much larger than that of electricity to GDP, averaging –1.8% annually. When the index of shift is computed, we see that sectoral shift slowed the decline of aggregate energy intensity until 1988 by offsetting some large increases in nonelectric energy efficiency. After 1988, sectoral shift accounted for nearly all (-1.4%) of the annual decline in aggregate intensity (-1.7%). However, in 1997 and 1998, aggregate intensity declined dramatically at –6.0% annually. From 1997 to 1998, sectoral shift caused a -2.7% annual rate of energy intensity, with an additional –3.3% remaining. In the previous 10 years, real intensity had averaged only -0.2% annual change.

Observations on Energy Intensity Changes from 1996 to 1998

Compared with trends in prior years, energy trends in the more recent years looked quite different. The recent years

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showed a marked acceleration of energy intensity decline. If we look back to the point where energy prices took major downward turn (1983 for electricity and 1986 for nonelectric energy), an interesting picture emerges.

During the15-year period of 1983-1998, the rate of aggregate electricity intensity change was -0.3%, about half of which was sectoral shift, and half was real intensity. During 1997 and 1998, electricity intensity changed by an annual rate of –1.8%. Sectoral shift doubled, from –0.13% to –0.26%. After accounting for the sectoral shift, we estimate the decline in real intensity as –1.6%.

For nonelectric energy use in the nontransportation sector, the rate of change in aggregate energy intensity was –1.3% from 1986-1998. Almost four fifths, -1.0%, was sectoral shift; the remainder of the change was decline in real intensity, -0.2%. Between 1996 and 1998, the impact of sectoral shift increased to –2.7%, almost a factor of three. Real intensity declined even more dramatically, to -3.3%.

To understand the significance of changes in 1997 and 1998 from past trends, we should consider the possible underlying economic effects of both the structural shift and the real energy intensity. First, the structural change in the economy toward more value-added, less energy-intensive sectors appears to have increased in recent years. Romm et al. (1999) suggests that the role of the Internet, or information technology (IT) in general, is important. We examine this opinion below in our underlying data. Second, real energy intensity showed some additional reduction relative to past years. There are many reasons that this might have occurred, despite falling energy prices. One reason is that investment as a percent of GDP was up significantly, which may have driven changes in the productivity component of real energy intensity. Another reason may be the success of government-sponsored, voluntary energy-efficiency programs, which may have started to show an impact. On the other hand, we consider that 1997 and 1998 energy use may have been driven by changes in weather-sensitive energy loads. We discuss each of these issues in turn.

Structural Change and Information Technology

The increase in sectoral shift occurred for both electricity and nonelectric energy intensity. The increase and overall magnitude in sectoral shift was much larger for nonelectric energy. This is not surprising, since the difference in sectoral energy intensity was much wider for nonelectric energy than for electric energy. It is the difference in energy intensities between sectors that was the underlying cause of the sectoral shift phenomenon. High value-added information sectors of the economy were much

Figure 2
Decomposition of Electric Energy Intensity

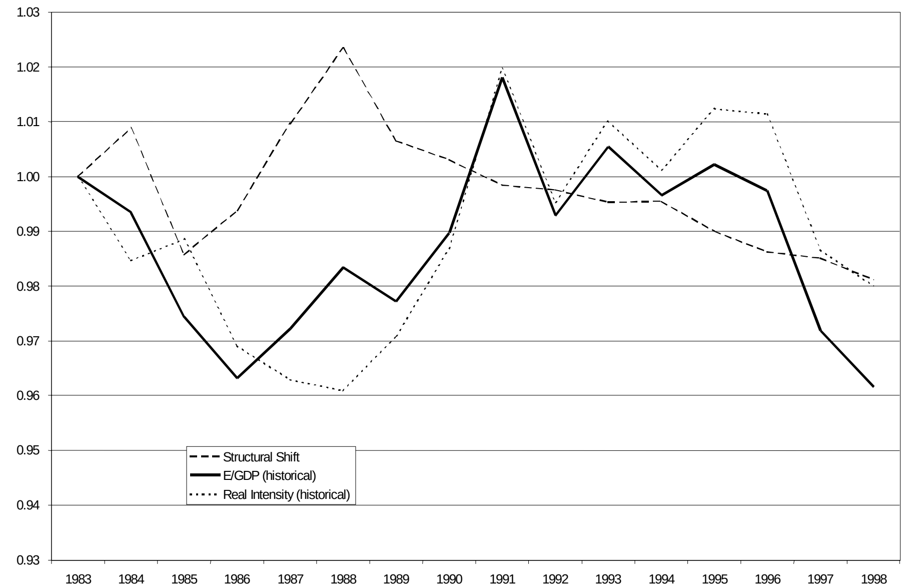
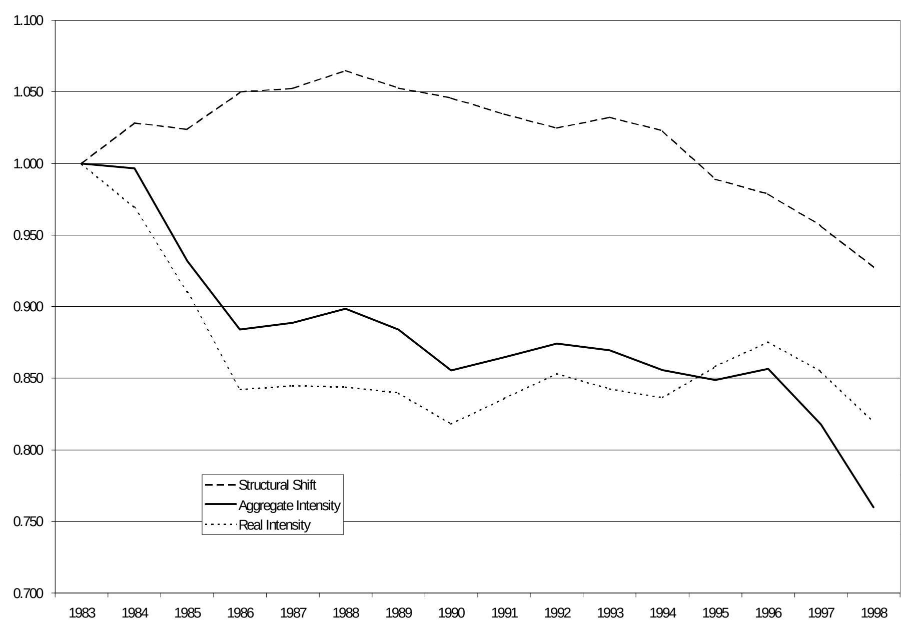


Figure 3
Decomposition of Nonelectric, Nontransportation Energy Intensity



lower in nonelectric energy than electric energy. These sectors grew most rapidly in the last few years.

The growth of the IT sectors has been cited anecdotally as an important driver of change in the U.S. economy. A report by the Department of Commerce (DOC 1999) identifies several IT sectors, many of which are included in the high-growth manufacturing sector taxonomy used in this analysis.[10] To see how these IT sectors may have driven results, we look at the growth rates of the IT vs. non-IT sectors in the LIEF "high-growth" manufacturing sector. We found that the high-growth manufacturing sector grew at an average annual rate of 5.8% from 1983 to 1998. The IT manufacturing component grew at 12% annually. The IT nonmanufacturing component grew at 3.5%, only slightly better than the overall economy (3.0%) and non-IT high growth sector (3.3%) and less than the commercial sector overall (3.6%). It appears that the IT growth strongly influenced the sectoral shift results.

Investment and Productivity

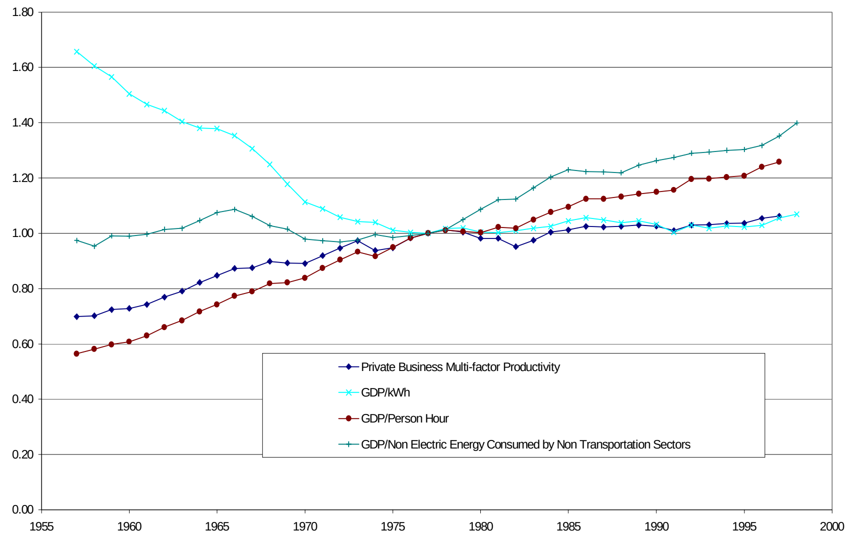
It is well understood that investment in new capital drives the productivity advances in the economy. Since energy intensity, energy per unit of output, is simply the inverse of productivity (measured as output per unit of input of energy or some other resource), it is helpful to examine overall productivity trends in energy and other inputs. Figure 4 shows the aggregate energy intensity measure discussed above represented as productivity measures. These are compared to measures of labor productivity and multifactor productivity (MFP).[11] In recent years, nonelectric energy productivity outpaced labor productivity. On the other hand, we see that electricity productivity was quite close to MFP.

MFP is typically viewed as an economywide measure of technical change. Other things being equal, one would expect single factor productivity to be about equal to MFP. Single factor productivity (e.g., labor or energy) may diverge from MFP if the intensity of other factors, particularly capital, raises the effectiveness of those other inputs. The BLS estimates that increased capital intensity contributed 0.4% to labor productivity between 1990 and 1997 (the last year for MFP data). This contribution compares to 0.5% average in MFP over the same period. Capital deepening, the addition of more capital per unit of labor through increased investment, is an important component of labor productivity. The impact on energy productivity depends on the substitution relationship between energy and capital.

Atkeson and Kehoe (1999) illustrate a "putty-clay" model where energy and capital are long-run substitutes. This view is also consistent with engineering studies of energy efficiency. This view suggests that capital deepening would tend to augment the MFP trend to improve energy productivity. On the other hand, capital requires energy to operate, so the rate of capital deepening would have to be compared to the differences in energy intensity in new capital.

If we simply compare the empirical growth rates from the nineties, we find MFP at about 0.5%; nonelectric and electric productivity, adjusted for sectoral shift, both average only about 0.2%. In the more recent years, we find that MFP was up sharply, averaging about 3.0% in 1994-1996. Energy productivity was also up, averaging 1.0% and 3.3% for electric and nonelectric, respectively. For nonelectric energy, the magnitude of MFP and nonelectric productivity was quite striking. The lower value for electric productivity suggests that capital deepening required additional electric energy use, but that the net effect was still an improvement in energy productivity.

Figure 4
Comparison of Single Factor and Multifactor Productivity Measures



Energy Efficiency Programs

There are many government- and nongovernment-sponsored programs for energy-efficient technologies. These include the Federal Energy Management Program (FEMP), the U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA) Energy Star Programs, Green Lights, and Climate Challenge Program. In addition, regulatory programs were implemented during the period we examine. We do not provide a comprehensive analysis of these programs but use estimates of the electricity savings from a small group of these programs to illustrate the magnitude of these savings, relative to our measured historical trends.

EPA has estimated the electricity consumption savings from the Energy Star and Green Lights programs. These programs, which began in the early nineties and have focused on the residential and commercial end-use sectors, saved an estimated 26.2 billion kWh in 1998. This amount is almost three times the savings from these programs only two years before in 1996 and about 1.3% of US retail sales of electricity in those sectors. If we plot the contributions of these voluntary program estimates on top of the real electricity intensity, we can see the difference that they began to make

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(Figure 5). At the same time, other voluntary energy-efficiency programs that showed a strong level of savings. A careful accounting for successes in each of those operations would serve to increase the distance between the actual reduction in electricity intensity and what "would have been."

Short Term Variation Due to Weather-Sensitive Energy Use

The changes in 1997 and 1998 described in this paper might be attributable to short-term fluctuations around a long-run trend. In particular, weather may have driven the year-to-year energy use patterns in a manner consistent with these results. To examine this, we regress the annual growth rates in electric and nonelectric real intensity against the change in heating and cooling degree-days. This approach should capture the weather-sensitive variation in the energy intensity, after our corrections for sectoral shift. Table 1 shows the results (t-statistic shown beneath the coefficient estimates). The intercept is the average growth rate in shift-adjusted energy intensity. The only statistically significant coefficient is for the effect of cooling degree-days on electric intensity, although the heating degree-day variable might be considered "marginally significant". Both variables have the correct sign; and the cooling degree-day is much larger, as expected by the growth in air-conditioning load over the last 15 years. Neither weather variable is significant in the nonelectric equation.

Since the electric intensity equation suggests that some of the variation in the shift adjustment is explained by weather, we wanted to see how well the equation predicts the last two data points. The actual values are –2.5% and –0.6% for 1997 and 1998, respectively. The predicted values are –0.6% and 0.3%, respectively. Collectively, the regression underpredicted the decline in electric intensity in the last two years by 2.8 percentage points. The nonelectric equation actually did a better job of predicting the 1997 and 1998 growth rates of –2.5% and –4.0%. The predicted values were –1.8% and –4.0%. However, the weak t-tests and the counterintuitive sign on the CDD variable suggests that this is not a strong contender to model variations in energy intensity.

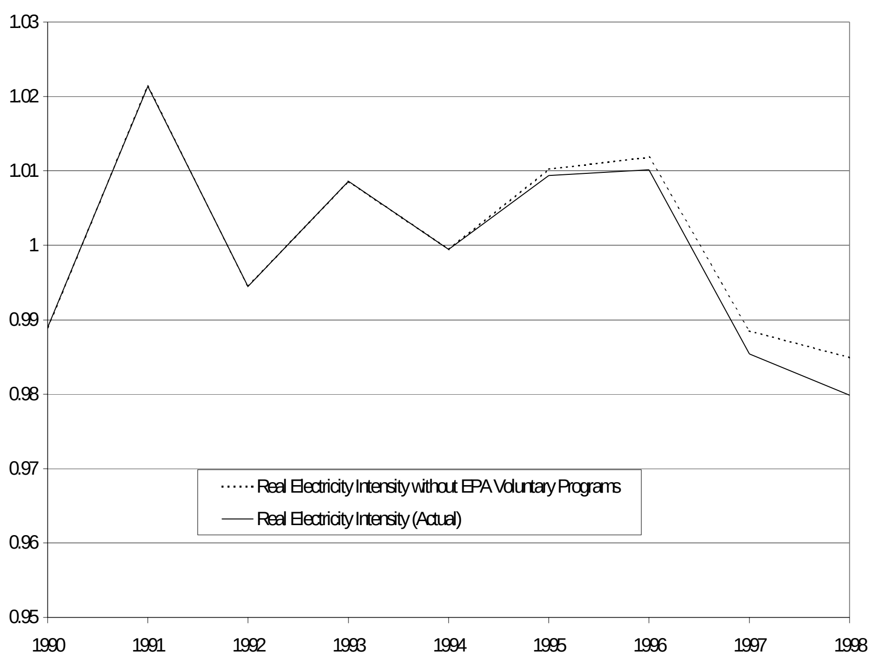
Table 1
Regression of Annual Growth Rates in Real Energy Intensity against Changes in Weather (t-ratio shown below coefficients)

		Change	
	Intercept	HDD	CDD
Electric	-0.10%	0.000019	0.000078
	-0.24	1.24	2.04
Nonelectric	-1.38%	0.00003	-0.00006
	-1.49	0.90	-0.68

Summary

If the economy charts a course toward less energy-intensive forms of economic activity, aggregate energy intensities will continue to fall. It is still too early to tell if the recent years of productivity and energy-efficiency improvements are the beginnings of a long-term trend in the U.S. economy. However, we identify a number of underlying effects that support this possibility. Although we believe that short-term fluctuations in weather did influence the weather-sensitive load (in particular, electricity), changes in heating and cooling degree-days did not adequately explain the change in real intensities. If these short-term, weather-related fluctuations do not explain the changes in energy intensity, then we speculate that rapid productivity improvements embodied in new capital investment may have generated net improvement in energy efficiency. Voluntary programs appear to play a measurable role in U.S. real (adjusted) electricity intensity through efficiency improvements. Although an information-based, service-based, and high-tech economy requires capital investment and uses energy to generate productivity improvements, the shift away from the far more energy-intensive manufacturing sectors has had a measurable effect on the U.S. aggregate energy intensity. At the same time, new and existing technology adoption is being accelerated in the buildings and offices of the same service and high-tech companies. If these effects continue, then recent trends in energy intensity may continue as well.

Figure 5
Example Magnitude of Savings from a Few Voluntary Energy Efficiency Programs



Footnotes

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[2] Energy Information Administration (1999).

[3] Andreassen and Chentrens (1999).

[4] For an early reference on the U.S. manufacturing sector, see Boyd et al. (1987). Greening et al. (1997) compares several methods for analyzing structural shift for 10 OECD countries.

[5] We cannot remove transportation activity in firms that own and operate internal vehicle fleets, only activity such as that associated with for-hire trucking, rail transportation as a flow of services is not included in GDP, so no adjustment is required for those activities.

[6] LIEF refers to the Long-Term Industrial Energy Forecasting model (Ross et al. 1993).

[7] See the appendix for technical details on the index number approach.

[8] These sectors exhibited very volatile patterns in the eighties. For example, the annual growth rate in the aluminum industry was –55% in 1985 and 44% in 1987. Although not as dramatic as aluminum growth rates, annual growth rates in steel and refining ranged from –21% to 28% in the late eighties and very early nineties.

[9] See appendix for details.

[10] Some of the "IT producing sectors" identified in the DOC report are communications and broadcasting, which we assign to the commercial sector, not manufacturing.

[11] Data shown are for private, nonfarm business.

[12] The term "rolling year" index is introduced by Lui to represent an annual, year-to-year, chain-weighted index rather than one that always references a base year, 0, and current year, T. This is the same index frequently employed by earlier authors but called simply a Divisia index (e.g., Boyd et al. 1987).

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Appendix: Index Number Methodology

By using the terminology introduced by Lui et al. (1992), we computed a rolling year Divisia index.[12] of the component of aggregate energy intensity that was due to sectoral mix for the years that the data were available. This index is given by:

$$(1+\Delta I_{mix})_{T-1,T} = \exp \sum_{j=1,J} \tfrac{1}{2}\left(\frac{E_{j,T-1}}{E_{T-1}} + \frac{E_{j,T}}{E_T}\right)\ln\left(\frac{S_{j,T}}{S_{j,T-1}}\right)$$

$$S_{j,T} = {}^{Y_{j,T}}\!/_{Y_T} \qquad (1)$$

where J is the total number of sectors. Energy use and output are denoted by E and Y, respectively. For simplicity we suppress any subscripts on E, although indices for electricity and non-electric energy are both computed. The index of total, or aggregate energy intensity is computed by:

$$(1+\Delta I_{total})_{T-1,T} = 1+\ln\left(\frac{E_T / Y_T}{E_{T-1} / Y_{T-1}}\right) \qquad (2)$$

The real intensity is computed by the identity:

$$(1+\Delta I_{total})_{T-1,T} = (1+\Delta I_{mix})_{T-1,T}(1+\Delta I_{real})_{T-1,T} \qquad (3)$$

It is well known that many index number approaches, including the one used here, suffer from a residual term. The index of real intensity derived from the identity in (3) would include this residual, so might not be an accurate measure. Ang and Choi (1997) propose a refined Divisia index, the Log Mean Divisia (LMD) index, which does not have this problem. The LMD was applied to the data used in this paper and the differences between the methods were empirically inconsequential. The rolling year Divisia results are reported.