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The Public Benefit of Energy Efficiency to the State of Massachusetts

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Preface

This report assesses the benefits of energy efficiency to the Massachusetts state economy, its environment, and its citizens. Because energy efficiency and its effects are difficult to measure directly, this analysis estimates energy efficiency through its effects on energy consumption and economic productivity (i.e., energy intensity, or the energy consumed per unit of output), while controlling for price, sectoral composition, and other factors. Further, this study is limited to improvements in the use of energy in the industrial, commercial, and residential sectors and does not include, for example, the transportation sector. Conceivably, improvements in energy usage in the commercial, industrial, and residential sectors could yield a number of benefits, including economic gains, improved productivity, improved quality of service, higher reliability, reduced pollution, and lower costs to consumers. This report addresses three of these benefits:

- Effects on the gross state product of energy efficiency improvements in the commercial and industrial sectors;
- Effects on air emissions of the improved utilization of energy in the commercial and industrial sectors; and
- Effects on households, particularly low-income households, of improvements in residential energy efficiency.

State audits have concluded that government investments in energy efficiency programs have affected energy intensity in Massachusetts, but this study does not establish this link; this study is limited in its ability to directly compare energy efficiency programs to actual improvements in energy efficiency.

The Energy Foundation, a partnership of major foundations interested in sustainable energy, funded this study.[1] The results are intended to inform policymakers and the general public about the benefits of energy efficiency programs in the state, to help these readers understand the role of the government in promoting these programs, and to provide useful information for national and local policymakers when they consider funding for energy efficiency programs in the future.

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[1] See http://www.ef.org/.

The authors would like to thank those individuals and organizations who helped in the research and preparation of the report. A partial listing includes Susan Coakley of Northeast Energy Efficiency Partnerships, Julie Michals of the Massachusetts Division of Energy Resources, Gene Fry of the Massachusetts Department of Telecommunications and Energy, and RAND's internal and external reviewers of the report.

This research was performed by members of RAND's Science and Technology Unit. RAND is a nonprofit, nonpartisan research organization. For further information on this report, please contact Mark Bernstein (markb@rand.org).

Contents

Figures

Tables

Summary

RAND, a nonprofit and nonpartisan research organization, has prepared this report with funding from the Energy Foundation, a partnership of major foundations interested in sustainable energy.

In this study, we estimate energy efficiency from measures of energy intensity (the energy consumed per unit of output) that have been controlled for sectoral composition, energy prices, and other factors.[2] In this report we address the public benefits of our estimate of energy efficiency to Massachusetts and find that improvements in energy efficiency in the commercial, industrial, and residential sectors are associated with:

- A benefit to the state economy since 1977 that ranges from $1,664 per capita to $2,562 per capita in 1998 dollars.[3]
- Approximately 11 percent lower air emissions from Massachusetts's share of stationary sources in the Northeast Power Coordinating Council.
- A reduced energy burden on low-income households.

This study measures the benefit to the state economy of improvements in energy efficiency in the industrial and commercial sectors from 1977 to 1997. It also predicts the potential future impacts of continued improvements in energy efficiency.

This report addresses four key issues and assumptions:

- This analysis shows that declines in energy intensity are associated with increases in gross state product (GSP), holding sectoral composition, energy prices, and other factors constant.
- When these other factors are held constant, changes in energy intensity can be an approximation of changes in energy efficiency. Thus, the conclusion is that improvements in energy efficiency are associated with improvements in gross state product.

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[2]Energy intensity is commonly defined as energy use per unit of output. Energy efficiency is commonly accepted as either reducing the amount of energy for a given output or increasing the output for a given level of energy.

[3]Except where otherwise noted, economic variables are deflated according to the Producer Price Index for Finished Goods, with base year 1982, and expressed in 1998 dollars (1998$).

- Government investments in energy efficiency programs may lead to improvements in GSP. At this point, we do not know how government programs affect the overall energy efficiency as used in the GSP analysis.
- Estimates of the cost per kilowatt-hour (kWh) saved of efficiency programs are compared to changes in GSP due to improvements in energy efficiency. These comparisons are for information purposes, and we do not assume that energy efficiency programs translate one for one into overall improvements in energy efficiency.

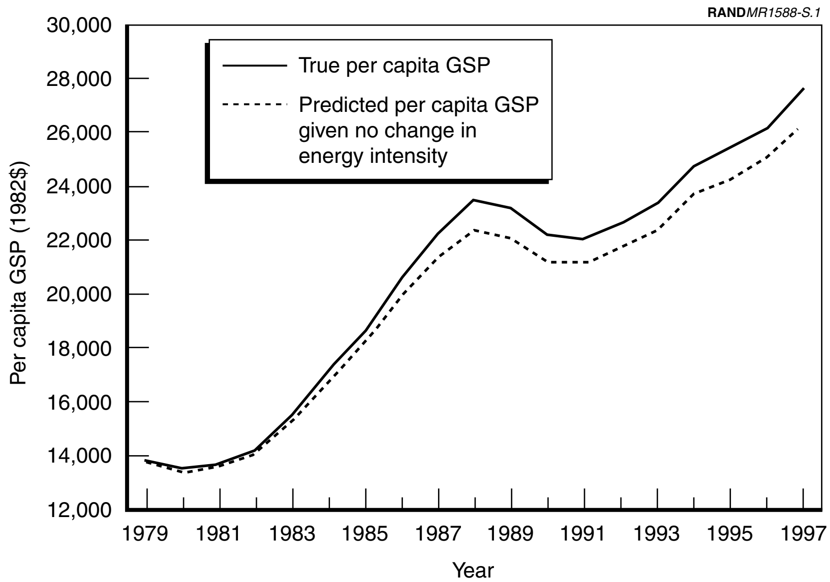
Effects on the State Economy

In this study, the GSP per capita is our indicator of economic performance. We use a conventional economic approach to measure the growth in GSP per capita, in which state economic growth is correlated with the stock and flow of capital and labor, government policies, and the characteristics of the population. The GSP measures the value of outputs from all economic sectors in the state. GSP per capita in Massachusetts grew by more than 100 percent from 1977 to 1997. The growth in GSP is due to a variety of factors, including but not limited to the industrial composition of the state, the growth of industry output, growth of commercial establishments, and demographic changes in the state.

We hypothesize that changes in energy intensity—the energy consumed per unit output— have also had an effect on the growth of GSP per capita (Figure S.1). By controlling for various exogenous factors such as price, industrial mix, new capital, and climate, we attempt to capture changes in energy intensity due to energy efficiency that have resulted partly from changes in government policy such as financial support for energy efficiency programs. However, establishing the causality between government energy efficiency programs and decreases in energy intensity as used in the economic growth analysis is beyond the scope of this project.

Energy Efficiency in Massachusetts: 1977–1997

The energy intensity of the industrial and commercial sectors in the state has declined considerably, though not consistently, since 1977. Despite an increase in total energy consumption in Massachusetts during that period, energy consumption per dollar of GSP has declined in both the industrial and commercial sectors. The contributing factors to these changes are many. Widespread use of new technologies and implementation of the state's building energy code may have supported, in part, the observed declines in energy



SOURCE: BEA, 1999.

Figure S.1—Actual GSP Per Capita from 1979 to 1997 in Massachusetts and GSP Per Capita in the Case of Constant Energy Intensity

intensity. Increases in the price of energy from the late 1970s to the mid-1980s contributed to the declines in energy intensity as well. In addition, the composition of the industrial sector changed over the period of study: The proportion of energy-intensive manufacturing industries in the state declined in the mid- to late-1980s, which reduced the aggregate amount of energy used per unit of output.

Our model includes controls for exogenous factors such as the composition of industry and energy prices to isolate more fully the improvements in energy intensity associated with energy efficiency. The model indicates that, when controlling for those factors, if there had been no decrease in energy intensity from 1977 to 1997 the Massachusetts economy would have been nearly 5 percent smaller than it was in 1997. In other words, the benefit in 1997 to the state economy associated with improvements in industrial and commercial energy intensity since 1977 ranges from $1,664 per capita to $2,562 per capita (Figure S.2). These changes in energy intensity that are associated with economic growth in the state were independent of the exogenous factors named above. These changes may be the effect of government policy in the form of energy efficiency programs. To draw a more solid conclusion, we need better data for national demand side management (DSM) expenditures. Absent this information, we take an indirect approach in evaluating these programs.

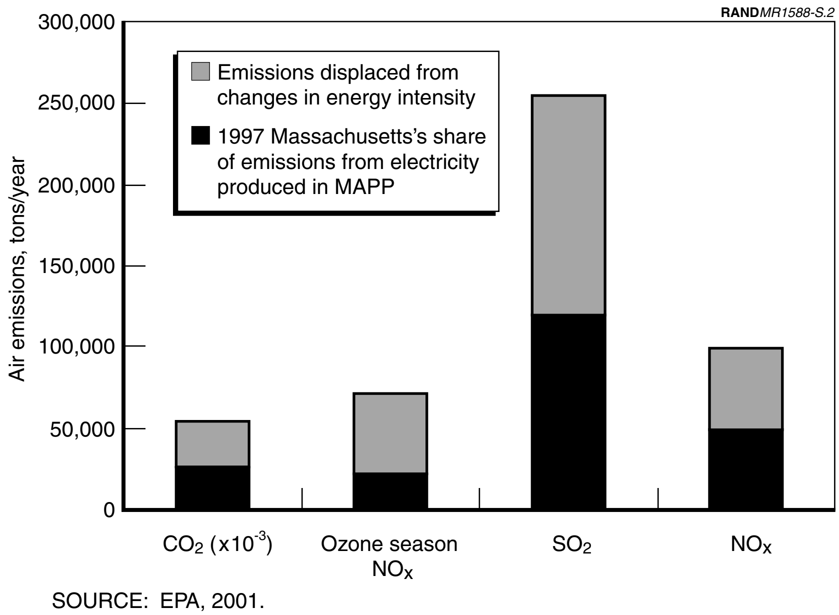


Figure S.2—Emission Reductions in Massachusetts

Ratepayer-funded energy efficiency programs have been an important part of the state's integrated resource management approach to energy policy since the 1980s; investment in DSM programs, including energy efficiency activities, has been shown to be a viable least-cost alternative for meeting the state's energy needs. Between 1991 and 1997, Massachusetts utilities reported that $746 million was invested in approximately 69,000 GWh (Gigawatt-hour) of energy savings, at an average rate of $10,805/GWh (DTE, 2001). Our model results show increases to GSP of $58.5 billion, corresponding to more than 1.3 million GWh of savings ($46,742/GWh) associated with decreased energy intensity during that same period. Massachusetts utility investments in energy efficiency in 1997 generally declined to less than two-thirds their 1991 level.

Energy Efficiency and the State Economy: 2000–2015

Population growth in Massachusetts over the past 20 years has increased demand for new energy supplies and has inspired investment in conservation programs. While Massachusetts has achieved significant benefits from reductions in energy intensity since the late 1970s, the future of energy use and energy efficiency programs in the state remains uncertain. Demographic projections predict that the state's greatest population growth will be in the coastal areas (i.e., Barnstable, Dukes, and Nantucket counties), but growth in the state's interior—especially Hampshire and Worcester counties—is also expected

(MISER, 1999). Although only about 15 percent of the population lives in rural areas, cooling and heating loads are greater in these areas; thus, businesses and residences located in these areas will operate at higher energy intensity than will comparable businesses and residences located in more temperate coastal areas. Lower energy prices in the long term, use of new electronic household and office appliances, and the increased energy load on space conditioning could lead to increased energy intensity in all sectors. The state's energy connection to other states via the northeast power grid also connects the state to the region's potential demand and reliability problems as well.

The analysis shows that, after controlling for various factors, reduced energy intensity is associated with economic growth. Energy intensity in the industrial and commercial sectors in Massachusetts declined overall from 1977 to 1997. In the period from 1977 to 1988, energy intensity decreased, followed by an increase in energy intensity from 1988 to 1993, and another decrease from 1993 to 1997. Looking to the future, if energy intensity were to reverse itself at half the 1977 to 1997 rate, GSP per capita in 2015 could be $649 per capita less than it would have been if energy intensity remained at its 1997 level. On the other hand, if energy intensity were to continue to decline at the overall 1977 to 1997 rate, the benefit to GSP in 2015 could be approximately $1,316 per capita. If energy intensity were to decline at the 1977 to 1990 rate, the benefit to GSP per capita could be approximately $1,986 per capita. Thus, continued declines in energy intensity, after controlling for various factors, could continue to benefit the state economy. Based on our economic methodology, these estimates of benefits of reduced energy intensity must be cautiously interpreted as upper bounds.

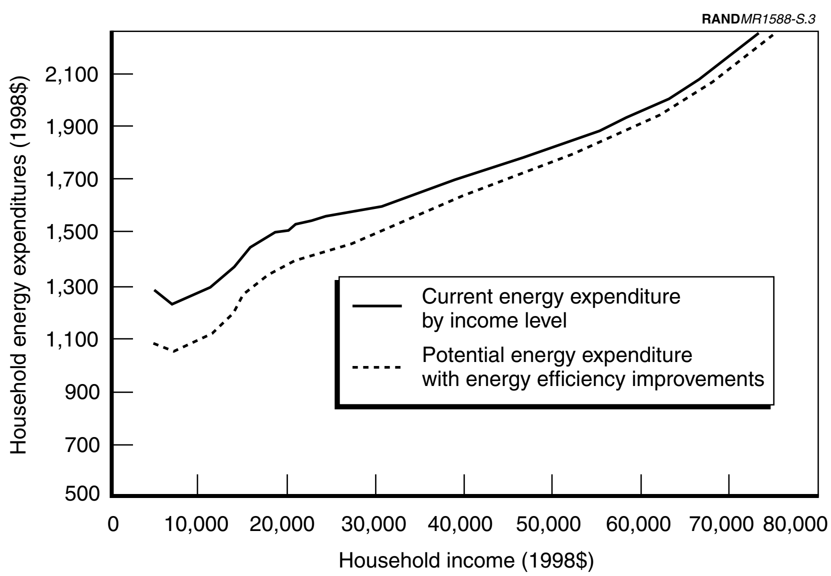
Environmental Benefits

One of many environmental benefits associated with improved energy efficiency is the effect on air emissions. In our analysis, we find that if energy intensity in the state had remained at 1977 levels, air emissions as a result of power consumption could be approximately 11 percent greater than current levels. Massachusetts receives its power from various sources in the northeast, hence the reductions in emissions are spread over the northeastern region. The pollution mitigated associated with reductions in energy intensity over the study period is approximately the total amount emitted in 1997 (Figure S.2). While motor vehicles are the primary contributors to air emissions, and the transportation sector has grown dramatically over the past 20 years, reductions in energy intensity in the commercial and industrial sectors have allowed Massachusetts to slow the increase in emissions despite increases in energy consumption throughout the state.

Benefits to the Citizens

Unlike energy intensity and GSP in the industrial and commercial sectors, there is no easily quantifiable parameter with which to evaluate the benefits of energy efficiency to the residential sector. Furthermore, statewide economic benefits of reduced energy consumption in the residential sector are uncertain: Modest increases in disposable income may not manifest themselves as large-scale economic benefits to the state. It is clear, however, that investments in energy efficiency do reduce household energy costs and that these investments are cost-effective. In Massachusetts, improvements in residential energy intensity and energy prices have reduced the average energy expenditures per capita in real terms from $860 in 1977 to $646 in 1997. These benefits accrue to Massachusetts's residents.

Energy efficiency has the potential to reduce household energy costs across all income levels (Figure S.3), but low-income households derive the greatest benefit from reduced energy expenditures. While low-income households spend less on energy than higher income households, the burden as a percent of income is higher for lower income populations. Thus, reduced energy costs in lower income households increase disposable income at a higher rate than in higher income households.



SOURCES: EIA, 1999b; Berry, Brown, and Kinney, 1997.

Figure S.3—Massachusetts Household Energy Expenditures

On average, low-income households nationwide spend 8 percent of their income on electricity, compared with 2 percent of a median-income household. In very poor households—those below 50 percent of the federal poverty level—23 percent of household income may be spent on electricity. A 1993 survey found that low-income households spend more for water heating than median-income households and spend almost as much on space heating, even though low-income homes are 40 percent smaller in size. Most of the energy-related services provided to these households are of low quality, using inefficient appliances and inadequate heating and cooling.

The opportunities for energy efficiency in the household can provide very direct benefits for low-income consumers. Energy efficiency programs at the household level provide two services: (1) they directly reduce monthly energy costs, thereby increasing the disposable income (after energy costs are paid) of the population (and consequently increasing the disposable income of the low-income population by a greater percentage than high-income households), and (2) they improve quality of life by improving the comfort level in homes.

Yet, federal LIHEAP (Low-Income Home Energy Assistance Program) allocations have declined by more than half since the mid-1980s and do not fully serve the targeted low-income population. In 1999, an allocation of $44.9 million, with emergency funds of $7.8 million served 105,543 households (DHCD 2001). More recent energy price shocks have created new political support for LIHEAP funding—but to serve only approximately 17 percent of the eligible population.

Conclusions

Declines in energy intensity are strongly associated with increased economic growth, improved air quality, and direct benefits to Massachusetts residents. Conversely, future increases in energy intensity could reverse these trends. While these declines have coincided with investments in energy efficiency, we do not specifically evaluate the link between energy efficiency programs and improvements in energy intensity.

Acronyms

ACEEE	American Council for an Energy Efficient Economy
Btu	British thermal unit
CO_2	Carbon dioxide
CO	Carbon monoxide
CPI	Consumer Price Index
DHDC	Massachusetts Department of Housing and Community Development
DHHS	U.S. Department of Health and Human Services
DOE	U.S. Department of Energy
DOER	Massachusetts Division of Energy Resources
DSM	Demand side management
DTE	Massachusetts Department of Telecommunications and Energy
EIA	U.S. Department of Energy, Energy Information Administration
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
GWh	Gigawatt-hour
GSP	Gross state product
kWh	Kilowatt-hour
LBL	Lawrence Berkeley National Laboratory
LBNL	Lawrence Berkeley National Laboratory
LIHEAP	Low-Income Home Energy Assistance Program
MISER	Massachusetts Institute for Social and Economic Research
MSBC	Massachusetts State Building Code
MW	Megawatt
NCAT	National Center for Appropriate Technology
NCLC	National Consumer Law Center

NERC	North American Electric Reliability Council
NO_X	Nitrogen oxides
NPCC	Northeast Power Coordinating Council
ORNL	Oak Ridge National Laboratory
O_3	Ozone
PM_{10}	Particulate matter, 10 microns or less in diameter
PPI	Producer Price Index
RECS	Residential Energy Consumption Survey
SIC	Standard Industrial Classification
SO_X	Sulfur oxides
WAP	Weatherization Assistance Program

1. Introduction

Background

In Massachusetts, ratepayer-funded energy efficiency programs have been in place since the 1980s. These programs were initiated as part of the state's least-cost energy planning strategy requiring regulated utilities to compare the cost-effectiveness of new generation versus reducing energy consumption. Demand side management programs typically include load management (e.g., peak-shifting strategies), but in Massachusetts these programs have included mostly energy efficiency activities such as retrofit and new construction programs, rebates for energy-efficient products, and consumer education. These programs provided several direct benefits to state residents such as energy savings, lower bills for consumers, and property improvements. Systemwide benefits included improved reliability and quality of service and postponement of new power plant construction. Public benefits including higher productivity and improved environmental quality were also realized (DOER, 1999).

In 1992, the Energy Policy Act expanded the authorization for nonutility companies to build and operate power plants that were established previously according to the Public Utility Regulatory Policies Act of 1978. And Federal Energy Regulatory Commission (FERC) Orders 888 and 889 in 1996 allowed competitive suppliers access to the bulk power transmission system. Thus, the industry continues to evolve toward a system of open competition according to various federal and state mandates. While the uncertainty associated with this transition has removed incentives for investment in energy efficiency as energy suppliers position themselves more competitively, the potential benefits of energy efficiency programs have not disappeared, even in a restructured market.

In Massachusetts, the Electric Restructuring Act of 1997 recognized that investment in energy efficiency has the potential to reduce overall electricity costs, lower harmful emissions, enhance system reliability, and stimulate the economy. The law established an energy efficiency charge over a five-year period (1998–2002) to support energy efficiency investments, including the installation of high-efficiency devices, construction of high-efficiency homes and buildings, and retrofit of existing structures. Further, the Massachusetts Division of Energy Resources (DOER) was directed to establish statewide energy efficiency goals and provide annual reports of progress toward these goals.

Research Approach

Independent of the studies performed by the Massachusetts DOER, we assess the public benefits that accrue from improvements in energy efficiency, and we evaluate past and potential future benefits to the economy of Massachusetts, its environment, and its citizens. We use panel data provided by the Department of Energy and Energy Information Administration, present a model of benefits derived over the period 1977–1997, and suggest potential future benefits through 2015 assuming continued encouragement of energy efficiency activities. Several benefits of energy efficiency have already been mentioned; this report addresses three of these benefits:

- Effects on the gross state product of energy efficiency improvements in the commercial and industrial sectors;
- Effects on air emissions of the improved utilization of energy in the commercial and industrial sectors; and
- Effects on households, particularly low-income households, of improvements in residential energy efficiency.

Note, however, that energy efficiency can be manifest in two complementary notions: An energy-efficient appliance in a home, for example, can use less energy to provide the same level of service, or it can use the same amount of energy to provide an increased level of service. In the first case, less energy is used and the reduction can be measured directly. In the second case, the same amount of energy is used, and to describe the increase in efficiency requires a measure of comfort or utility—characteristics that elude succinct and accurate definition and measurement. Energy efficiency, then, is a difficult metric to use directly.

In this report, we use measures of energy intensity as a proxy for energy efficiency. Defined broadly, energy intensity is the energy used per unit of output or unit served. An economy-wide indicator of energy intensity may be the energy per gross state product (GSP). In the commercial sector, where the primary energy load is for lighting and space conditioning, an appropriate measure of energy intensity may be energy use per square foot, perhaps accounting for occupancy and employee hours. In both these examples, changes in energy intensity reflect inverse changes in energy efficiency: When energy intensity decreases, energy efficiency increases. However, a change in energy intensity does not necessarily reflect a change in energy efficiency. In the industrial sector, for instance, a change in energy use per dollar of gross state product may be due to changes in the mix of industries in the state or an increase in the price of energy rather than the investment in new equipment or energy-efficient technologies. Energy efficiency, in this context, is defined only as those changes in energy intensity in the industrial and commercial sectors that are not due to economic or sectoral factors such as energy price, capital investment, and climate.

The approach used in this study follows that of a previous RAND study for the California Energy Commission that examined the public benefit of energy efficiency to the state of California (Bernstein et al., 2000). Similarly, our analysis here adopts a macroeconomic view of the Massachusetts economy with commercial and industrial energy intensity as key independent variables and GSP as the dependent variable. We attempt to control for several potentially confounding factors such as price, industrial mix, new capital, and climate. The empirical specification and results for Massachusetts are detailed elsewhere (Bernstein et al., 2000), and summarized in the Appendix to this report. However, additional research is necessary to evaluate the validity of the underlying assumptions and the robustness of the economic analysis to modeling error. A second aspect of our analysis quantifies the effect of reduced energy intensity in the commercial and industrial sectors on air quality in Massachusetts.

In addition to our analysis of GSP improvements due to energy efficiency (i.e., energy intensity that has been controlled for various factors) in the commercial and industrial sectors, we examine energy efficiency benefits in the residential sector. Unlike the commercial and industrial sectors, the value of energy efficiency to the residential sector is not directly quantifiable. Therefore, we examine a number of benefits to Massachusetts households due to energy efficiency including financial savings, increased comfort, and increased energy services. We focus our analysis of the residential sector on low-income households, due to their disproportionate energy burden relative to income level.

While the transportation sector also accounts for a large and increasing portion of energy consumption in Massachusetts, analysis of transportation sector energy use is beyond the scope of this study.

Together, these analyses provide useful evidence for estimating the value of energy efficiency to Massachusetts.

In summary, this report addresses four key issues and assumptions:

- This analysis shows that declines in energy intensity are associated with increases in GSP when holding sectoral composition, energy prices, and other factors constant.
- When these other factors are held constant, changes in energy intensity can be an approximation of changes in energy efficiency. Thus, the conclusion is that improvements in energy efficiency are associated with improvements in gross state product.
- Government investments in energy efficiency programs may lead to improvements in GSP. At this point we do not know how government programs affect the overall energy efficiency as used in the GSP analysis.
- Estimates of the cost per kWh saved of efficiency programs are compared to changes in GSP associated with improvements in energy efficiency. These comparisons are for information purposes, and we do not assume that energy efficiency programs translate one for one into overall improvements in energy efficiency.

2. Trends in Massachusetts Energy Intensity, Demand, and Environmental Factors

Energy Intensity and Energy Consumption Drivers

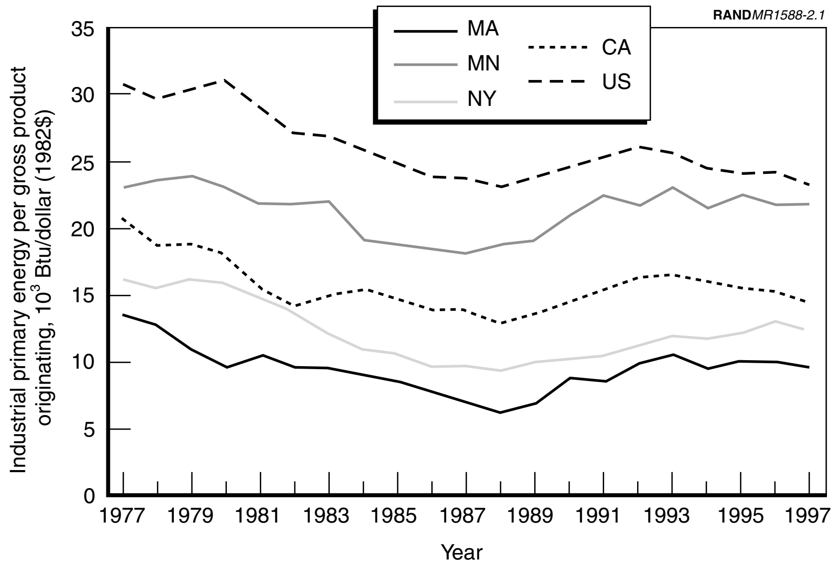
The following is a brief description of the past trends in energy intensity, as well as energy consumption drivers, in Massachusetts, comparable states, and for the United States in general. These trends illustrate the energy setting in Massachusetts and in the national context, within which we have conducted our analysis and from which we can interpret our results. For comparison to Massachusetts, the states of Minnesota, New York, and California were selected.

Industrial Sector

The industrial sector is that subdivision of the economy that comprises manufacturing, agriculture, mining, construction, fishing, and forestry. Its components can be identified by their Department of Commerce Standard Industrial Classification (SIC) codes corresponding to these economic activities. In addition, the DOE (U.S. Department of Energy) has used a number of indicators of energy intensity to characterize changes in the energy consumption pattern in the industrial sector. These include energy use per gross product originating, per value added, per value of production, and per industrial production (EIA, 1995a). In our analysis, we use energy consumption per gross state product originating from the industrial sector. In this section, the energy intensities reported have not been controlled for price of energy, sectoral composition, or other factors, and thus may include combined effects of price, capital, labor, and other factors besides energy efficiency.

Figure 2.1 is a plot of energy intensity in the industrial sector in Massachusetts, Minnesota, New York, and California from 1977 to 1997. In Figure 2.1, we see that industrial energy intensity in Massachusetts remained below that of its peer states and the nation as a whole during this period. Industrial energy intensity remained generally stable but declined between 1977 and 1988.

Differences in energy intensity can be explained, in part, by the mixture of industries within the industrial sector. Certain industrial activities require

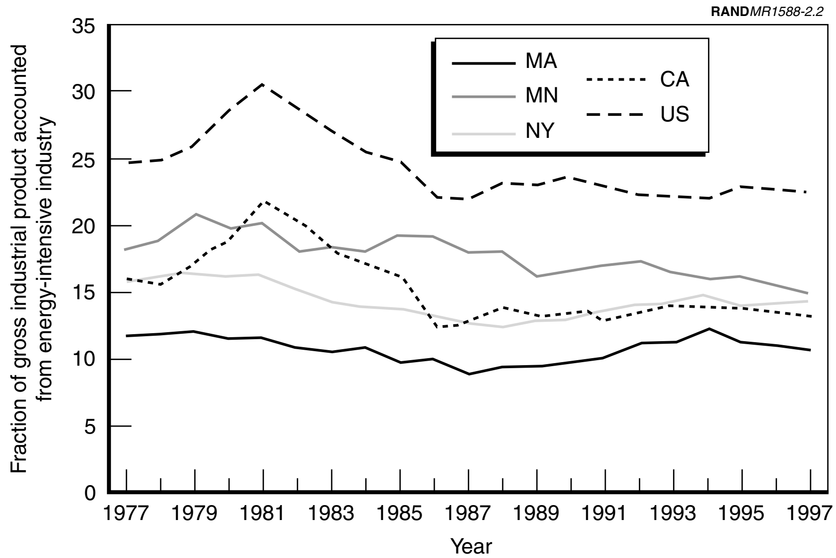


SOURCES: EIA, 1999a; BEA, 1999.

Figure 2.1—Industrial Energy Consumption Per Gross State Product

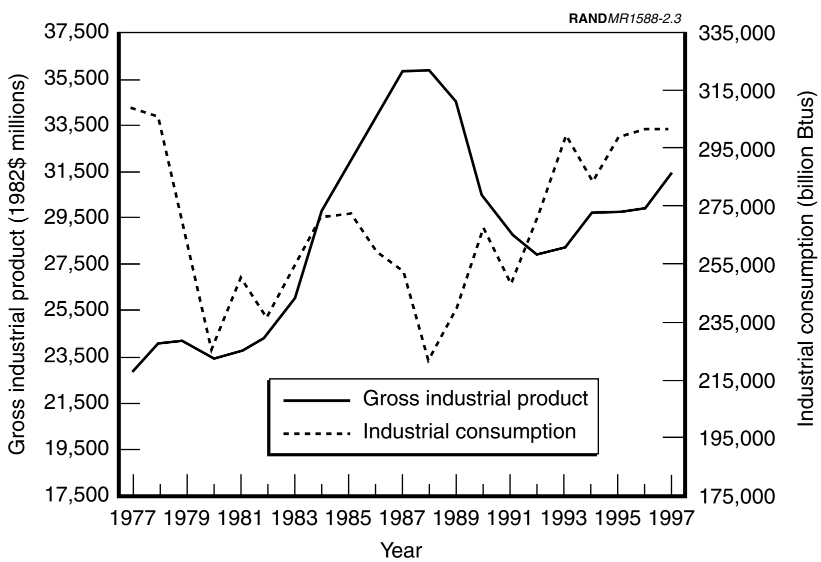
a significantly greater input of energy per dollar of output than others. Energy-intensive industries include mining (SIC 30000); stone, clay, and glass (SIC 51320); primary metals (SIC 51330); paper products (SIC 52260); chemicals (SIC 52280); and petroleum products (SIC 52290). Figure 2.2 is a plot of the fraction of the gross industrial product due to energy-intensive industry from the four states of interest from 1977 to 1997. One can see from the plot that in comparison to its peers and the national average, the larger share of the industrial product of Massachusetts has not originated from industry that is energy intensive, and the fraction has remained relatively stable since 1977. In fact, the economy in Massachusetts is characterized primarily by service-oriented industries (i.e., the commercial sector), with industrial manufacturing accounting for only about 15 percent (BEA, 1999) of the state's economic output. Nonetheless, shifts in the composition in the industrial sector are an important control factor in our analysis.

Recall that energy intensity is the ratio of a sector's consumption to its dollars of production; therefore, this ratio will, from year to year, increase if consumption increases at a faster rate than production. Likewise, if production increases at a faster rate than consumption, the energy-intensity measure will decrease. From Figures 2.1 and 2.2, a decline in industrial energy intensity occurred in the 1980s that coincided with a shift away from energy intensive industry during this period. Figure 2.3 shows in more detail the overall consumption and production



SOURCE: BEA, 1999.

Figure 2.2—Fraction of Gross Industrial Product from Energy Intensive Industry



SOURCES: EIA, 1999a; BEA, 1999.

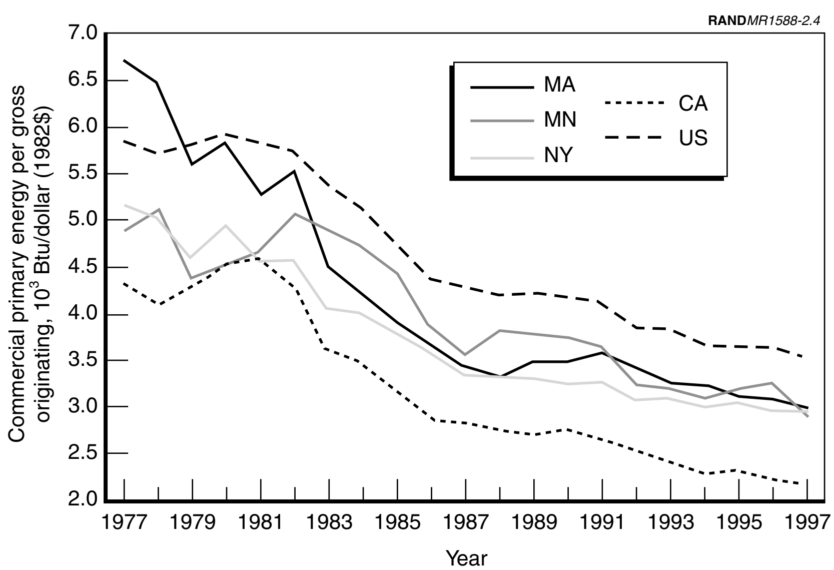
Figure 2.3—Total Industrial Consumption and Gross Industrial Product, Massachusetts

of the Massachusetts industrial sector from 1977 to 1997. While the shift away from energy-intensive industry may account for an increase in production relative to consumption in the 1980s, decreased energy intensity in the late 1970s and mid-1990s also occurred and may be the result of more efficient industrial production during those periods.

Historic declines in energy intensity have corresponded with high energy prices and implementation of DSM programs. Since the late 1980s, however, Massachusetts has seen industrial energy intensity rise, corresponding to a reduction in price of energy, the early stages of reductions of DSM programs, and economic growth. Of these factors, high energy prices are not expected to persist, and without other incentives to reduce consumption, industrial energy intensity may continue to rise.

Commercial Sector

The commercial sector is considered to be that economic sector that is "neither residential, manufacturing/industrial, nor agricultural" (EIA, 1998b). As in the case of the industrial sector, a number of indicators of energy intensity may be used to characterize the commercial sector's utilization of energy. Figure 2.4 is a plot of the energy consumption per gross state product in the commercial sector in Massachusetts, Minnesota, New York, California, and the United States Commercial energy intensity in Massachusetts has generally declined since the late 1970s.

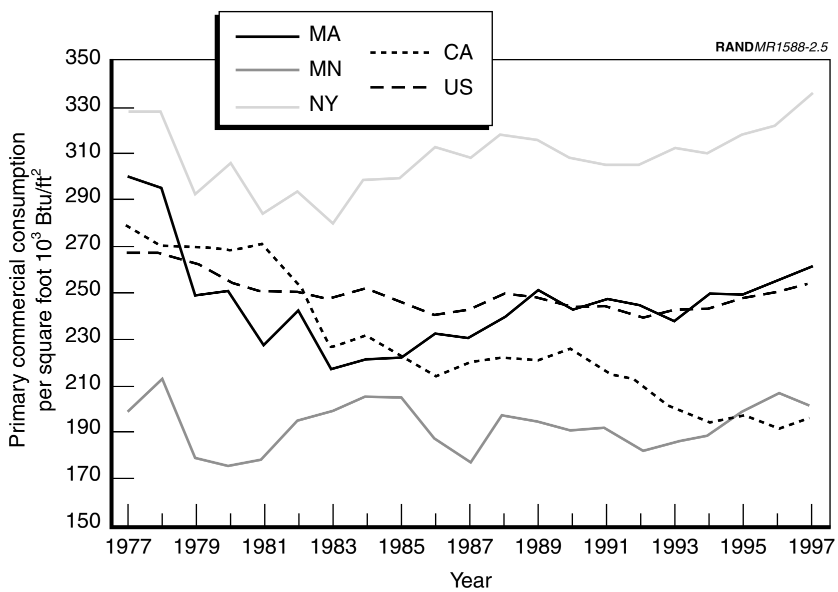


SOURCES: EIA, 1999a, 1999b; BEA, 1999.

Figure 2.4—Commercial Energy Consumption Per Gross State Product

The commercial sector uses most of its energy for space conditioning and lighting. According to the EIA (1998b), "commercial buildings include, but are not limited to, the following: stores, offices, schools, churches, gymnasiums, libraries, museums, hospitals, clinics, warehouses, and jails." The energy used for space conditioning and lighting is a function, in part, of the amount of floor space in the commercial sector. Therefore, an alternative measure of energy intensity in the commercial sector is energy use per square foot. Figure 2.5 illustrates the primary energy consumption per square foot in the four states of interest from 1977 to 1997. Inspection of Figure 2.5 reveals that commercial energy consumption per square foot in Massachusetts has generally declined since the 1970s. The general decline may be due to several factors, including the implementation of the uniform Massachusetts State Building Code (MSBC) adopted in 1975. The MSBC applies to all new construction and certain work in existing buildings. Note, however, that energy consumption per square foot has risen in Massachusetts since the mid-1980s, while consumption per square foot in states such as California and the national average continued to decrease.

One explanation for this increase in commercial energy consumption per square foot is that widespread use of energy-efficient technologies in commercial buildings has not kept pace with growth in the commercial sector, and a number of devices used in commercial buildings escape regulation under the MSBC.



SOURCES: EIA, 1999a; F. W. Dodge, 1999.

Figure 2.5—Primary Commercial Energy Consumption Per Square Foot of Nonresidential Floor Space

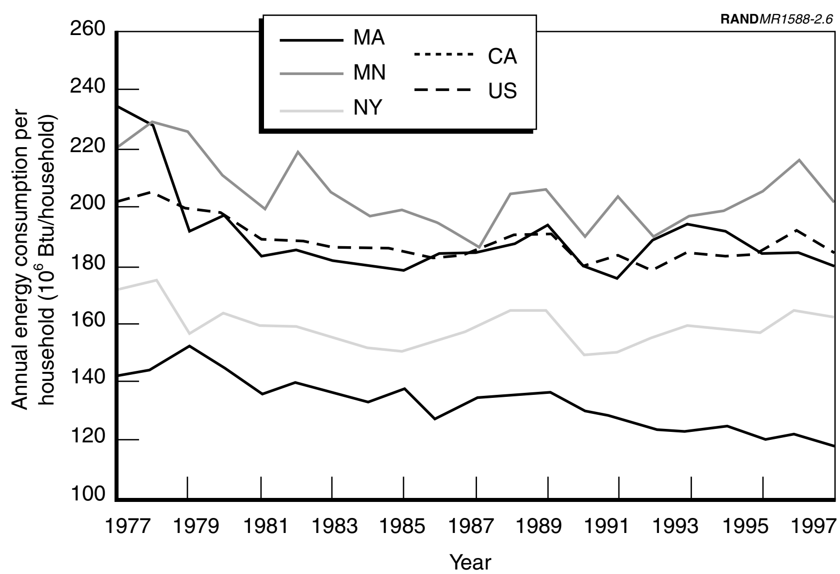
Another possibility is that growth in the western part of the state, beyond the more temperate coastal area, has increased space-conditioning loads. These factors, as well as potentially lower energy prices in the future, may contribute to increased commercial energy intensity in the future.

Residential Sector

Although we do not analyze the residential sector in a macroeconomic analysis of the benefits of energy efficiency, a review of general trends in household energy consumption in Massachusetts is helpful in understanding the residential energy setting and the factors that drive consumption.

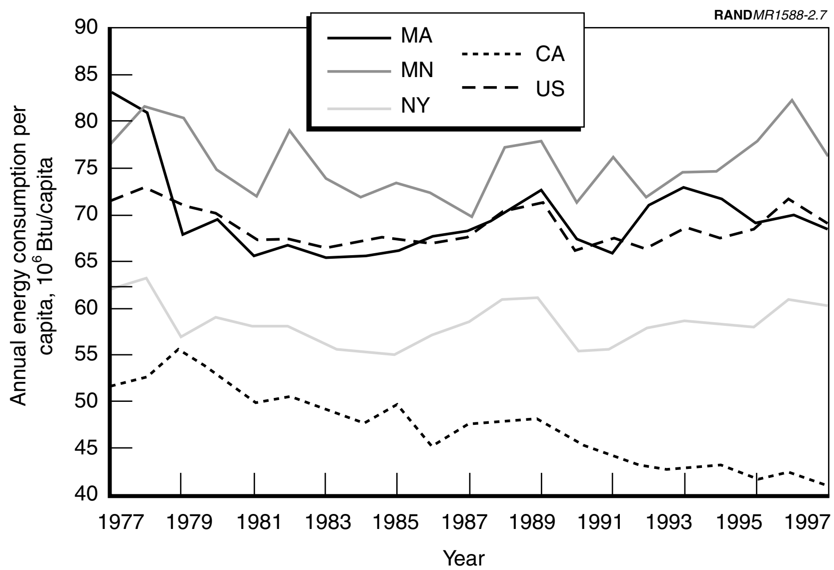
Figure 2.6 shows the annual primary energy consumption per household while Figure 2.7 illustrates the annual primary energy consumption per capita from 1977 to 1997. Both indicate a general decline in energy intensity over the study period, likely due in part to compliance with energy codes, especially for new construction. Through examinations of the expenditures on energy in the residential sector, we will connect these declines in energy intensity to benefits to several classes of residential energy customers.

Demographic projections (Figure 2.8) predict the greatest population growth in the coastal areas (i.e., Barnstable, Dukes, and Nantucket counties), but growth in



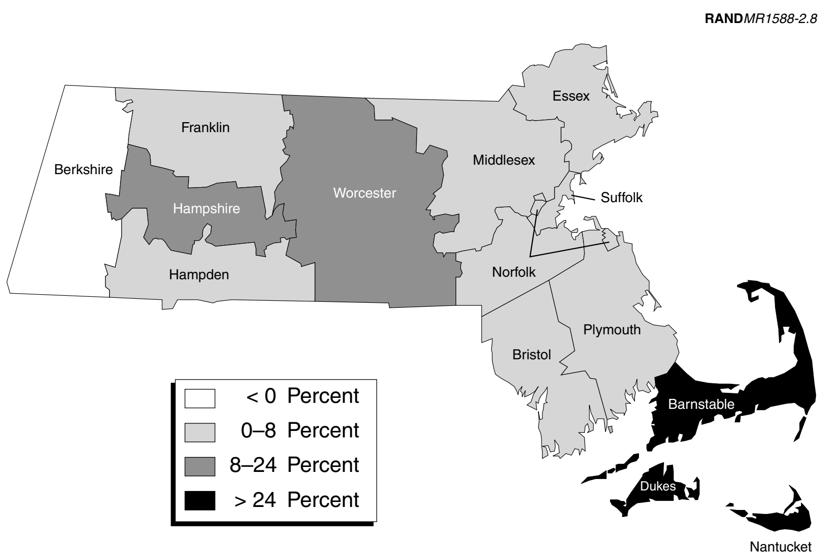
SOURCES: Census, 1999; EIA, 1999b.

Figure 2.6—Annual Per Household Energy Consumption for the United States and Selected States



SOURCES: Census, 1999; EIA, 1999b.

Figure 2.7—Annual Residential Per Capita Energy Consumption for the United States and Selected States



SOURCE: MISER, 1999.

Figure 2.8—Forecasted Population Growth by County: 2000–2010

the state's interior—especially Hampshire and Worcester counties—is also expected (MISER, 1999). Although only about 15 percent of the population lives in rural areas, cooling and heating loads are greater in these areas; thus, businesses and residences located in these areas will require higher energy intensities than comparable businesses and residences located in more temperate coastal areas.

Energy intensity in the residential sector may continue to follow the decline seen since the late 1980s and 1990s, as new commercial buildings are built to comply with the energy code. Lower energy prices in the long term, use of new electronic household and office appliances, and increased space-conditioning load could lead to increased energy intensity in all sectors.

Energy Demand and Reliability

Massachusetts is within the Northeast Power Coordinating Council (NPCC) region of the North American Electric Reliability Council (NERC) system. The NPCC includes southeastern Canada (i.e., Ontario, Quebec, and Maritime provinces) and the New England states (i.e., Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut). Massachusetts is a net importer of electricity (EIA, 2001) and as such is subject to regional reliability and demand conditions. In the year 2000, system reliability in the NPCC was maintained, but only by the acquisition of emergency power during peak periods through interregional emergency actions. Through 2009, energy demands in the NPCC are anticipated to grow at an average annual rate of 1.2 percent (NERC, 1999). For New England during this period, the average annual electrical energy growth rate forecast for the summer-peak load in New England is 1.52 percent, the winter peak load growth rate is 1.39 percent, and total energy is 1.51 percent (NERC, 1999). Assumed in the forecasts for New England is a 1,600 MW decrease in the otherwise expected load for 2009 due to nonparticipant generation and participant DSM programs. According to NPCC criteria, New England resources will have adequate capacity for future demand if planned future generating capacity additions are fully integrated into the New England transmission system and if forecasted loads are not exceeded (NERC, 2000).

Reliability in the NPCC, and throughout North America, will depend in large part upon the smooth transition from bundled monopoly services to competition in wholesale and retail markets, according to federal and state restructuring laws. Obtaining the benefits of a competitive marketplace requires facing the challenges associated with interconnection, market power, and stranded cost recovery, while maintaining the reliability of the power system.

In addition, environmental regulations also constrain the reliability of the electrical system. As energy consumption leads directly to air emissions, national ambient air quality standards must be met according to the Clean Air

Act and the State Implementation Plan, while simultaneously meeting the region's growing electrical demand. Electricity generated by Massachusetts utilities in 1998, which accounted for approximately 56 percent of electricity production in the state in that year, was generated from petroleum (38.5 percent), coal (31.4 percent), and nuclear power (21.9 percent), with the remainder of electricity being generated by gas and hydropower (EIA, 2001). Over the next decade, further requirements will be designed to meet national ambient air quality standards. Compliance likely will require significant outages of fossil-fueled generation to install the required nitrogen oxides (NO_x) control devices (NERC, 2000.)

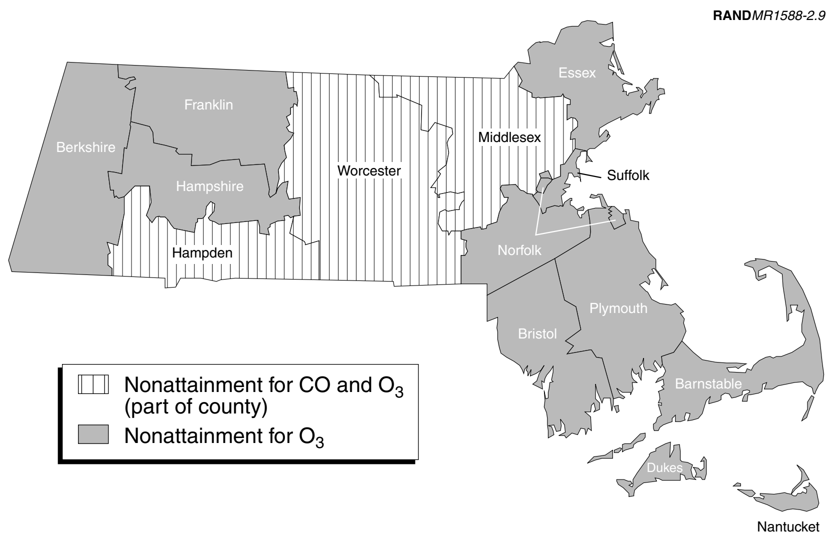
Environmental Factors

Growth in Massachusetts has affected its demand for energy and its environmental quality. Air quality, in particular, has decreased, especially near population centers. Further population growth in these areas will exacerbate problems in air quality due to energy use. As in other states, the primary contributor to decreased air quality throughout Massachusetts is motor vehicles, but emissions from electricity production and industry also contribute. In-state electricity production depends in large part on petroleum and coal-fired thermal generators; in fact, the proportion of electricity produced by coal-fired generation has remained relatively stable since 1988 (EIA, 2001).

From the late 1980s to the mid-1990s, SO_2, NO_x, and CO_2 emissions from electricity generation generally decreased in Massachusetts but have been on the rise since then (EIA, 2001). Based on data from the Environmental Protection Agency, Figure 2.9 illustrates current areas of nonattainment status for pollutants regulated under the Clean Air Act (EPA, 2001). As such, parts of Hampden, Worcester, and Middlesex counties are in nonattainment for carbon monoxide (CO), and the entire state is in nonattainment for atmospheric ozone (O_3). It is important to note that the air quality is time dependent, and periods of poor air quality are the result of both natural and anthropogenic causes. Continued growth is expected in counties where air quality is already a concern—in both eastern and western parts of the state.

Conclusions

Energy use in Massachusetts has increased in the past and will continue to increase in the future. Energy planners in the state must continue to consider options for meeting this growing demand, beyond that which has been provided by the state's existing generation system and imports. Yet even with increased



SOURCE: EPA, 2001.

Figure 2.9—Massachusetts Nonattainment Areas for CO and O_3 by County in 2001

consumption, energy intensity has generally decreased in all sectors over the past 20 years. In the following chapters, we show that the declines in energy intensity in the industrial and commercial sectors have had cost-effective positive benefits for the state economy, its environmental quality, and its citizens. While the interplay of government regulations, efficiency programs, prices, climate, and economic factors that contributed to historic declines in energy intensity may not be present in the future, we argue that the potential benefits associated with decreased energy intensity may continue, especially with the encouragement of energy efficiency in the state.

3. Energy Efficiency in the Industrial and Commercial Sectors, Economic Growth, and Environmental Benefits

This chapter presents our analysis of the benefit of energy efficiency in the industrial and commercial sectors on the economic output of the state, or GSP, from 1977 to 1997. In addition, we compare this benefit to the investments and savings of selected utility energy efficiency programs over this period. We also speculate as to potential future benefits of energy efficiency in the commercial and industrial sectors. Finally, we examine some of the environmental benefits of energy efficiency.

Energy Efficiency and the Massachusetts Economy: 1977–1997

The econometric analysis estimates the average effect of energy intensity and other factors on GSP in the 48 contiguous states (see the appendix). To determine the estimated effects for Massachusetts, we use the national averages on data from 1977 to 1997 as a baseline for determining the effects of changes in energy intensity, while controlling for energy price, sectoral composition, and other factors, on per capita economic growth in Massachusetts.

The analysis shows that changes in energy intensity are associated with the growth of GSP. From 1977 to 1997, GSP per capita in Massachusetts grew from $18,089 to $36,239 (1998$). According to the analysis, if energy intensity had remained constant at the 1977 level over this period, then GSP per capita would have been 4.8 percent less than its actual 1997 value. Figure 3.1 shows the actual evolution of GSP per capita and the predicted evolution in the case of constant energy intensity (1982$).

As shown in Table 3.1 this economic growth is equivalent to $1,664 per capita in 1997. When we examine the impact of energy intensity across states with industrial characteristics similar to Massachusetts, we find that the impact on GSP per capita is potentially larger than the national average. In this case, the increase in GSP per capita associated with reductions in energy intensity that has been controlled for various exogenous factors is $2,562 per capita.

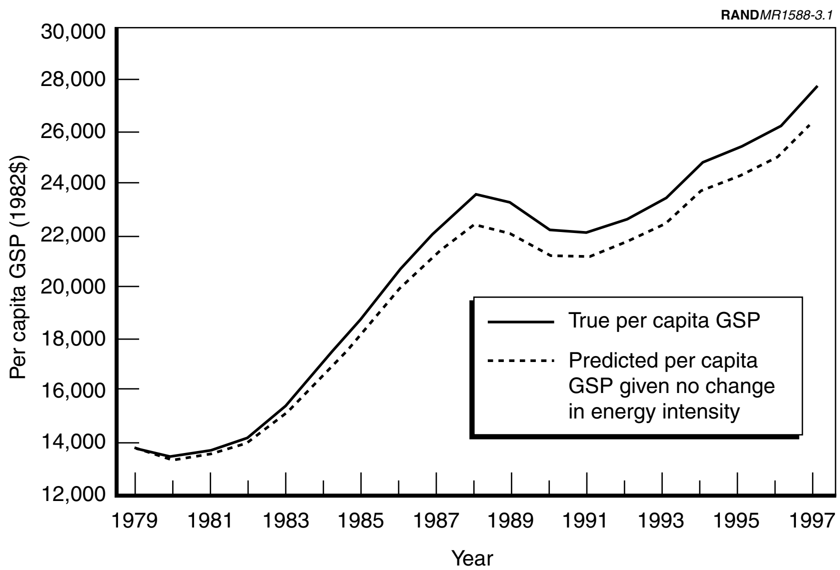


Figure 3.1—Actual GSP Per Capita and GSP Per Capita in the Case of Constant Energy Intensity

Table 3.1

The Estimated Effects of Energy Intensity Improvements on the Massachusetts Economy

Source of Energy Intensity Coefficients Used in Analysis	Increase in GSP Per Capita	Increase in Total GSP in 1997 (billions)	Increase in Total GSP, 1977–1997 (billions)
National average	$1,664	$10.2	$111.0
States similar to Massachusetts	$2,562	$15.7	$165.3

The Value of Energy Efficiency Programs to Massachusetts

Throughout the study period there have been state- and utility-sponsored energy efficiency programs in Massachusetts. Often, these programs target specific end users and end uses such as lighting, home insulation, and facility retrofitting. The purpose of the programs is to promote cost-effective energy efficiency improvements in the state's industries, stores, offices, farms, and homes. To draw solid conclusions about the impact of energy efficiency programs on GSP, we need to include in our model data related to the expenditures for these programs as an explanatory variable. Absent this data, we take an indirect approach. In this section we compare increases in GSP to estimates of energy and monetary savings reported for state-sponsored energy efficiency programs to the state of Massachusetts. We recognize that the extent to which the programs have actually contributed to declines in energy intensity is unknown.

The previous section showed that, since 1977, reductions in energy intensity are associated with economic gains of $1,664 per capita, or approximately $10.2 billion in 1997. In fact, the cumulative gains over the entire period amount to approximately $111.0 billion. Likewise, we can estimate the amount of energy that would have been consumed had energy intensity remained constant over the time period, and we describe this savings in terms of dollars per unit of energy saved ($/GWh, gigawatt-hour). This number serves as a rough benchmark for comparison to DSM program costs. Note that these are savings due only to energy intensity improvements in the commercial and industrial sectors, and it is assumed that the energy saved is the result of changes in energy intensity independent of the control factors. From modeled benefits to GSP over the study period, in terms of $/GWh, and utility investment and savings rates, also in terms of $/GWh, we can make an informative comparison of benefits to costs. Note however, that we cannot make conclusions about the effectiveness of utility conservation programs, as we have not shown a specific link between investment in energy efficiency programs and effects on energy intensity.

Unfortunately, the data that describe the expenditures and energy savings of DSM programs are limited. Wide-scale reporting by the utilities generally did not occur prior to 1990. Therefore, we used data describing investment and savings for commercial and industrial programs for the period 1991–1997, as reported by the state's utilities and compiled by the Massachusetts Department of Telecommunications and Energy (DTE, 2001). Utility estimates of energy savings have been reported in terms of lifetime savings, and according to the DOER (1999), average program life is 14 years. RAND has not independently verified these estimates.

According to utility reports, we find that the average cost of these programs begun between 1991 and 1997 was approximately $10,805/GWh (1.1 cents/kWh), while the estimated effects to Massachusetts associated with all changes in energy intensity over the time period (1991–1997) was $46,742/GWh (4.7 cents/kWh). If utility estimates of investment and savings in DSM programs are, in fact, indicative of investment and savings in energy efficiency activities in Massachusetts and of the programs' effect on energy intensity, then such a comparison favors these programs. However, to determine the relationship between energy efficiency programs and changes in energy intensity, and to identify an actual return on investment, would require additional analysis. It is important to note that the notion of a return on investment in this context applies to the state economy as a whole and not to those who participated in energy efficiency programs in particular.

Although we do not know the true benefits of DSM programs with certainty, nor the effect of such programs on energy intensity, we may ask how accurately the utilities must report investment and savings in order for the programs to be cost-effective compared to our benchmark. Our analysis suggests that had these programs saved only 23 percent of the savings that were reported, the unit cost of energy ($/GWh) of such programs would have been roughly equivalent to our predicted savings to the state. Thus, the programs were cost-effective, even if their energy savings were overestimated by a factor of four, or if program costs were four times as much.

Future Benefits of Energy Efficiency to Massachusetts

In the previous section, we have shown that improvements in energy intensity, perhaps influenced by energy efficiency programs, have been associated with economic benefits to the state. In what follows, we project our results into the future (2015) and determine the future value of energy efficiency while making some assumptions regarding future changes in energy intensity.

In the past, improvements in energy efficiency often coincided with improvements in industry practice and investment in new equipment and processes. Yet with the rapid advance of technology and changes in energy services, it is possible that the gains in energy intensity in Massachusetts may be reversed. Therefore, we consider a set of future scenarios based upon possible changes in energy intensity in the commercial and industrial sectors. These projections cannot be tied directly to the funds that may be spent on energy efficiency measures in the future, but they do allow us to speculate regarding the continued benefits of energy efficiency to the Massachusetts economy.

Inspection of Figure 2.1 and Figure 2.4 suggests three general trends in energy intensity in Massachusetts. From 1977 to 1997, energy intensity in both the industrial and commercial sectors generally declined. However, two phases of energy intensity changes occurred during this period. From 1977 to 1988, energy intensity in Massachusetts decreased, but from 1988 to 1993, the average energy intensity increased. The changes are due in part to shifts in industrial mix—from energy-intensive resource and manufacturing industries (e.g., mining, metal, paper, and chemical processing) to less energy-intensive high-tech commercial activities (e.g., software development, financial services, and retail). Gains in energy efficiency have also contributed. Figure 3.2 presents the three scenarios

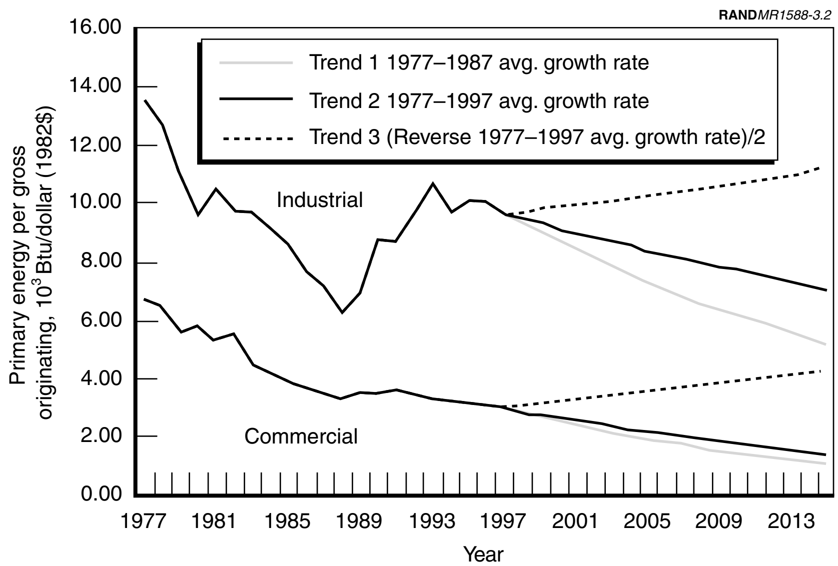


Figure 3.2—Trends of Primary Energy Intensity in Massachusetts in the Industrial and Commercial Sectors

as extrapolations of trends in energy intensity changes for the industrial and commercial sectors.

In one scenario, energy intensity decreases as it did from 1977 to 1988. In the second scenario, energy intensity declines moderately according to the 1977 to 1997 average change. In the third scenario, energy intensity increases at half the rate if the overall 1977 to 1997 trend were to reverse itself. Using the national average coefficients calculated previously, we estimate expected economic growth for the three scenarios. In addition, we calculate low, medium, and high estimates for the effect of energy intensity on the state economy based on the standard error of our estimate. Recall that these coefficients are derived from our analysis and controlled for price, sectoral composition, and other factors. We compare these nine results against a baseline that assumes no change in energy intensity from 1997. Table 3.2 presents the nine estimates of the changes in GSP per capita associated with the combined effects of changes in commercial and industrial energy intensity under these three scenarios.

Our analysis shows that if energy intensity in the commercial and the industrial sectors reverses by half its 1977–1997 trend, the cumulative net loss in GSP per capita by 2015 could be about $649 per capita compared to the baseline. On the other hand, the analysis shows that reductions of energy intensity can continue to have large-scale economic benefits to the state. If energy intensity in

Table 3.2

Estimates of Future Economic Benefits of Reductions in Energy Intensity to Massachusetts in Terms of Per Capita GSP

Source of Energy Intensity Coefficients Used in Analysis	1997 Benefits	1977–1990 Trend Large Decrease in Energy Intensity	1977–1997 Trend Moderate Decrease in Energy Intensity	1977–1997 Trend (Reverse/2) Increase in Energy Intensity
National Average—High Impact	$2,163	$3,442	$2,322	–$1,134
National Average—Middle Impact	$1,663	$1,986	$1,316	–$649
National Average—Low Impact	$1,158	$557	$323	–$161

Massachusetts continues to decline at its average rate from 1977 to 1997, we could expect an additional increase in GSP per capita between $323 and $2,322 per capita by 2015, depending on the estimated benefits of decreased energy intensity. Better still, if energy intensity in Massachusetts declines according to the recent 1977 to 1990 trend, we could expect an additional increase in GSP per capita between $557 and $3,442 per capita, depending on the estimated benefits of decreased energy intensity. Note that these measures of energy intensity include the controls we used in our analysis.

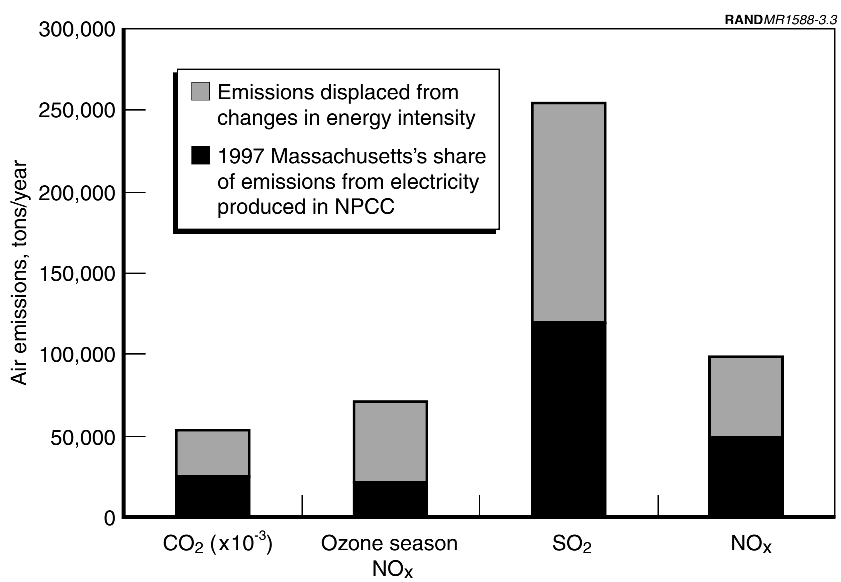
If energy intensity increases rather than decreases, as it did in 1977–1997, and if energy efficiency programs achieve improvements similar to those made from 1977 to 1997, the potential benefit could be $1,965 per capita (the difference of the average values in column four and column five of Table 3.2.). In a state of 6.3 million residents (Census, 2001), the potential gain in GSP in 2015 could range from $3.1 billion (using the low values under these same assumptions) to $12.5 billion (using the high values under these assumptions).

Environmental Benefits of Reduced Energy Intensity

Environmental policies and regulatory requirements associated with electricity generation are many and complex. Potential environmental impacts such as air emissions, hazardous waste, poor water quality, and land use disputes are all areas of concern.

In this analysis we focus on the effects of energy consumption on air quality. In particular, energy consumption directly leads to the air emissions, which include various air pollutants regulated under the Clean Air Act (e.g., particulate matter, SO_2, NO_x, CO) and CO_2. We calculate emissions reductions due to reduced energy intensity in the industrial and commercial sectors, after considering control factors, from the total electricity used in each sector, in comparison to the electricity consumption if energy intensity had not changed since 1977. We also consider the fact that Massachusetts receives its power from a variety of sources in the NPCC region; thus, emissions rates and the state's total emissions from electricity consumption are calculated from the aggregate emissions in that region. Finally, we use the aggregate emissions from fossil-fueled generators in that region since those would be the emitters reduced or increased in any one year.

If we consider an aggregate emissions level from fossil-fueled power production in the NPCC, reduced energy intensity in the commercial and industrial sectors displaced approximately 11,000 tons of SO_2 and 4,000 tons of NO_x in 1997. In addition, carbon dioxide emissions were reduced by approximately two million tons in 1997 by reduced energy intensity in commercial and industrial sectors in Massachusetts. The total amount reduced over the study period associated with reductions in energy intensity is equal to approximately the total amount emitted in 1997 (Figure 3.3).



SOURCE: EPA, 2001.

Figure 3.3—Emission Reductions from Electricity Produced in the NPCC Due to Changes in Energy Efficiency in Massachusetts

Air quality has decreased in Massachusetts, particularly near growing population centers. As shown in Figure 2.9, parts of some counties are in nonattainment of CO standards, and the entire state is in nonattainment for atmospheric ozone. Further population growth will exacerbate problems in air quality due to energy use. While the primary contributor to decreased air quality throughout Massachusetts is motor vehicles, emissions from electricity production and industry also contribute. Our analysis shows that reductions in energy intensity have not only produced economic benefits but also slowed the increase in air emissions throughout the region.

4. Benefits of Energy Efficiency in the Residential Sector

While changes in GSP associated with changes in energy intensity may indicate the benefit of commercial and industrial energy efficiency to the state, no convenient macroeconomic indicator is available that can quantify the benefits to the state economy of energy efficiency in the residential sector. We can, however, look at the benefits for households, so the following discussion describes some of the benefits that have come to Massachusetts households due to reductions in household energy intensity. These include financial savings, increased comfort, and an increased number of energy services. Our comparison of household energy consumption and expenditures in Massachusetts, with those of other states and across income levels, suggests that reductions in household energy intensity have benefited the state's citizens, particularly those of low-income households in less temperate parts of the state.

Residential Energy Consumption Characteristics

As in the industrial and commercial sectors, changes in energy consumption in the residential sector are associated with a number of factors that include climate, size of household, age of the home and its appliances, the presence and enforcement procedures of a residential energy code, and the price of energy. Previously, we presented two indicators of energy efficiency for the aggregate residential sectors in Massachusetts, Minnesota, New York, California, and the United States in general: residential energy consumption per household (Figure 2.6) and residential energy consumption (Figure 2.7) per capita.

Table 4.1 lists the percent changes in per capita primary energy consumption in Massachusetts, Minnesota, New York, and California according to Ortiz and Bernstein (1999). Also included is the year in which the state adopted a residential energy efficiency building code. Accordingly, primary residential energy consumption per capita in Massachusetts has fallen by nearly 13 percent since the 1970s.[1] Similarly, in Minnesota and New York, primary energy

[1]Primary energy consumption describes consumption of energy with respect to its source, as opposed to consumption at its end use. Primary energy, thus, exceeds end use energy in that it also accounts for system and transmission losses.

Table 4.1

Changes in Residential Primary Energy Consumption Per Capita Excluding Transportation

State	Year of Residential Energy Code Implementation	Percent Change in Per Capita Energy Consumption from 1970–1978 Average to 1988–1995 Average
MA	1975	–12.8
MN	1976	–3.3
NY	1979	–3.5
CA	1978	–19.2

SOURCE: Ortiz and Bernstein, 1999.

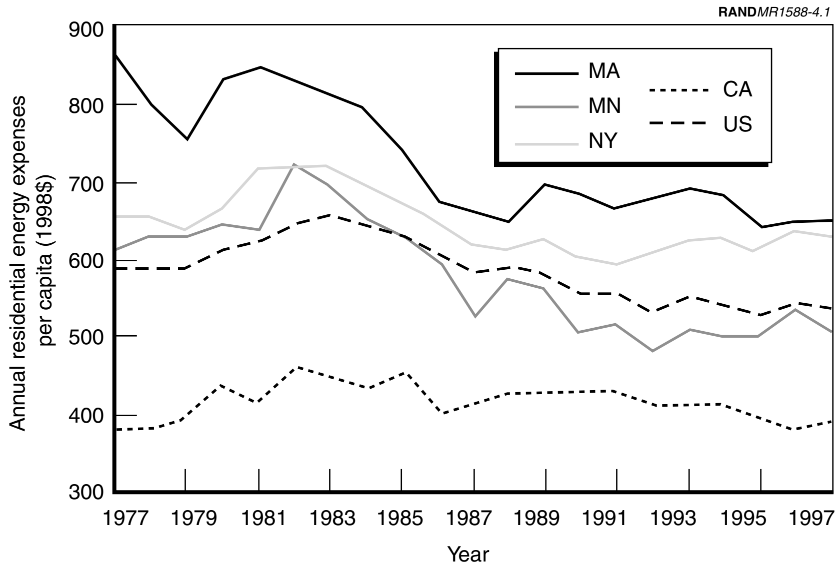
consumption per capita has decreased by more than 3 percent, and California has seen declines in excess of 19 percent. Thirty-five states in the United States have residential energy codes, and the average change in annual per capita energy consumption for the 48 contiguous states over the same period has been a 1.7 percent increase.

In Massachusetts, the changes in per capita energy consumption have reduced real per capita energy expenditures in the state. The history of real residential energy expenses appears in Figure 4.1. The 1997 residential energy expenses per capita in Massachusetts were $646[2] (EIA 1999a). The 1997 expenses represent a 25 percent decline in real energy expenses from the high of $860 (1998$) in 1977. The $214 annual per capita savings per year from 1977 to 1997 translates into a gross savings to Massachusetts residents of $1.3 billion. This comprises a combination of improvements in both energy efficiency and energy prices, which have generally decreased in real terms during the study period.

Energy Efficiency and Low-Income Households

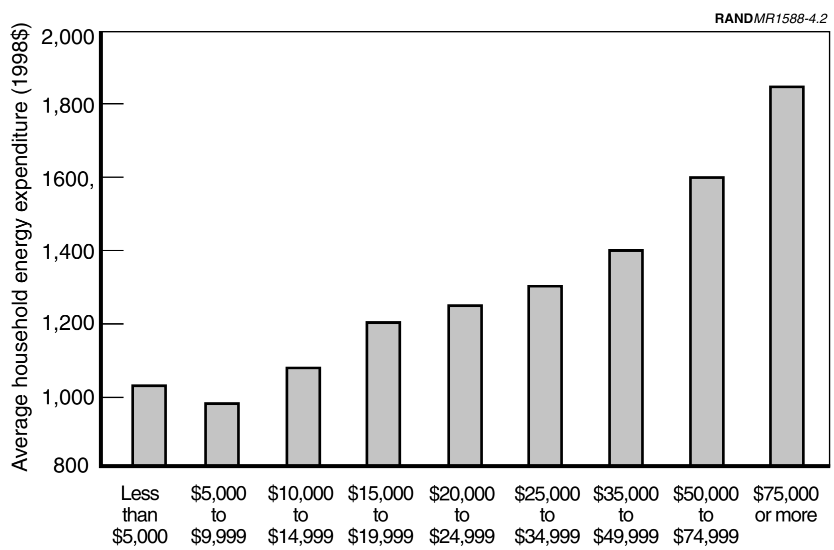
Energy needs differ among households, and their annual expenses for energy vary between approximately $1,000 and $2,000. Higher-income households tend to use more energy than lower-income households; however, the percentage of household income devoted to energy services is greater for low-income households. According to the 1997 Residential Energy Consumption Survey (RECS), the national average energy expenditures in 1997 for a household in the $5,000 to $9,999 income bracket were $985 ($1,000 in 1998$). However, for a household in the $75,000 and above income bracket, the expenditures were $1,864 (1998$); see Figure 4.2. Thus, average energy expenditures in the highest

[2]For comparison in real terms, the energy savings to residential consumers have been adjusted according to the Consumer Price Index and are reported in 1998 dollars (1998$).



SOURCE: EIA, 1999b.

Figure 4.1—Real Energy Expenses Per Capita in the Residential Sector in Massachusetts

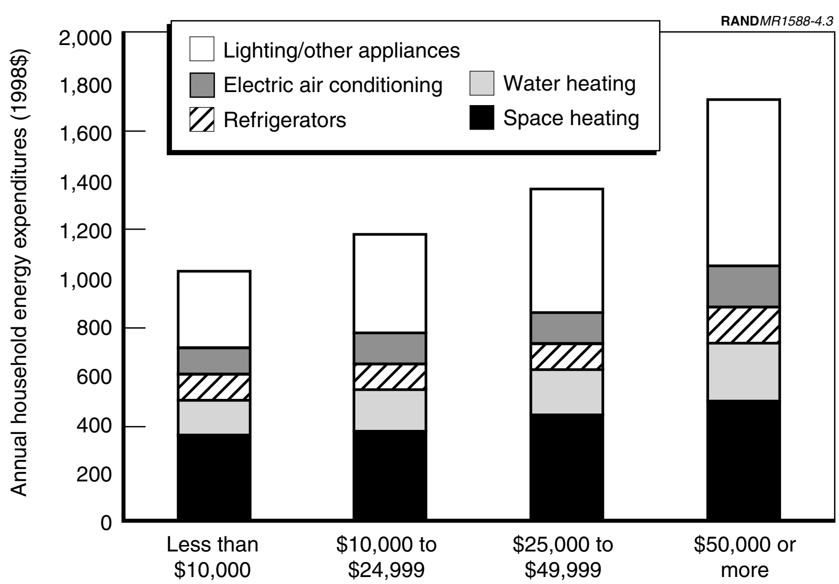


SOURCES: EIA, 1999b.

Figure 4.2—Nationwide Average Annual Energy Expenditures Per Household by Income Level

income group are almost twice that of the lowest income group, and their income is more than seven and a half times greater.

Furthermore, the realization of any savings in the residential sector is a function of the pattern of energy utilization in the household. When we compare expenditures by end use, we find that as much as two-thirds of energy-related expenditures are for the principal end uses of space conditioning, water heating, and refrigeration (see Figure 4.3). Consider these end uses to be essential energy services since they are shared across all income classes. The nationwide average expenditures per household for these services was $725 in 1997 for households with incomes less than $10,000, and $876 for households with incomes between $25,000 and $49,999—a 20 percent increase for a three-to-five-times greater household income. Savings, therefore, in essential energy services will be, with respect to total household energy expenses, more beneficial to the lower-income household than to other households, and the comfort and utility derived from essential energy services will be more sensitive to energy price and equipment efficiency in lower-income households than in higher-income households. As a result, energy savings may also have greater effect on disposable income of lower-income households. For a more complete survey of low-income household expenditures on energy, refer to Bernstein et al. (2000). In general, we conclude that while residential energy efficiency improvements provide benefits to all households, lower-income households are especially sensitive to energy costs, and so the benefits may be more significant.



SOURCES: EIA, 1999a.

Figure 4.3—Nationwide Average Annual Energy Expenditures by End Use and Household Income

The disproportionate energy burden already borne by these households is exacerbated by their relatively inefficient use of energy; the housing occupied by low-income households tends to be older than the average and therefore designed and built in a less energy efficient manner and equipped with less energy efficient fixtures and appliances. A study of low-income households found that 64 percent of households with less than $5,000 annual income have ceiling insulation, compared with 91 percent of households with more than $50,000 annual income, and that 14 percent of the former group versus 5 percent of the latter group have a refrigerator more than 20 years old (Chandrasekar et al., 1994). Among residences heated primarily with natural gas, those built since 1980 use 43 percent less energy than those built between 1940 and 1979 (DOE/EIA 1995a).

Overall, the poverty rate in Massachusetts (10.7 percent in 1997) is below the national average of 13.3 percent in 1997 (Census, 2001). However, the poverty rate in 1997 for Hampden County was estimated at 16.6 percent and for Suffolk County at 20.7 percent (MISER, 1999). The low-income population in the central and western part of the state, in particular, experiences greater heating and cooling needs than those in the more temperate eastern coastal region. Figure 4.4 shows the percentage of people living in poverty in counties of Massachusetts.

In general, people in rural households in western Massachusetts tend to live in an area of more extreme climates and have limited natural gas service, so they

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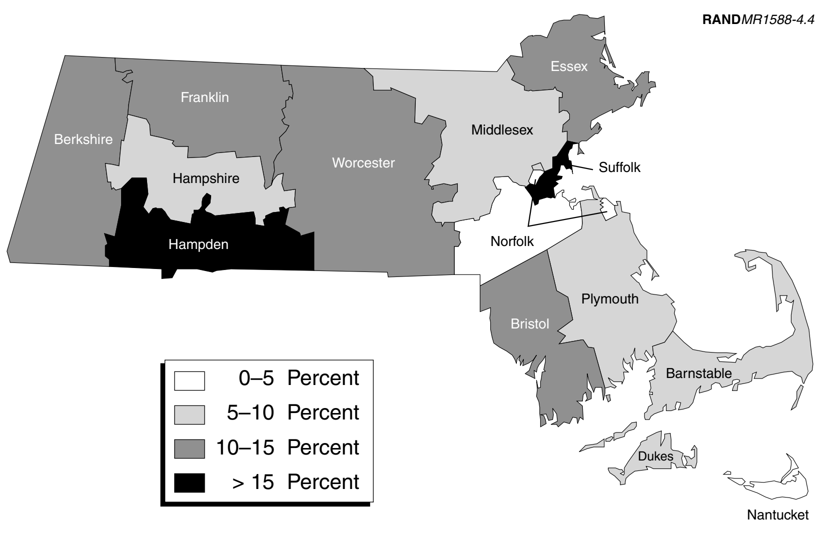


SOURCE: Census, 2001.

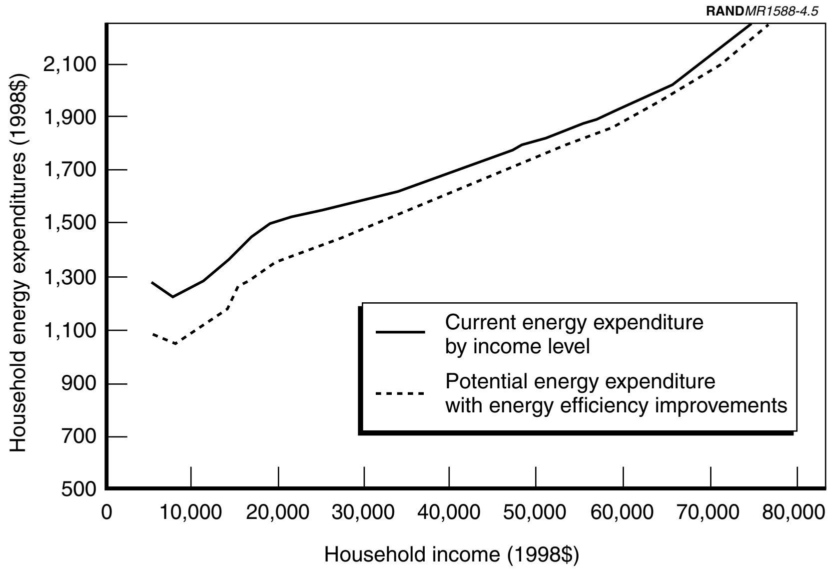
Figure 4.4—Percentage of Families in Massachusetts Living in Poverty

must rely on more expensive propane gas and less efficient electric heating. Furthermore, they must use electricity for services such as pumping water and outdoor lighting that are provided by municipalities in urban areas. Thus, relative energy burdens on low-income households in Massachusetts remain large: Low-income households (below 150 percent of federal poverty level) spend more than 19 percent of their income on energy, whereas less than 3 percent of income is spent on energy in median-income households (NCLC, 1995). Generally, Massachusetts is a summer-peaking area within the NPCC, yet winter heating bills generally exceed summer cooling bills, and greater heating and cooling expenses are incurred outside of the temperate coastal regions; for example, the average electricity bill for low-income households during the summer of 1992 was $407 in Springfield, but only $339 in Cambridge. During the winter of 1992/1993, the average electricity bill increased by four dollars in Springfield, but decreased by about four dollars in Cambridge (Colton, 1994).

Overall, the typical low-income household (below 100 percent of federal poverty level) in Massachusetts spends $1,450 per year on energy, compared with an average for median-income households of $1,775. Based upon estimates of energy expenditures by income level (EIA, 1999b) and estimates of savings associated with energy efficiency improvements such as weatherization,[3] Figure 4.5 shows the energy expenditures in Massachusetts households by income level, and the potential reduction of energy expenditures with energy efficiency improvements. Note that the gap widens for lower-income households accounting for the fact that lower-income homes are generally older and of poorer construction. Figure 4.6 shows the energy burden (expenditure as a percentage of income) on Massachusetts households by income level and the potential reduction of this burden associated with improvements in energy efficiency.

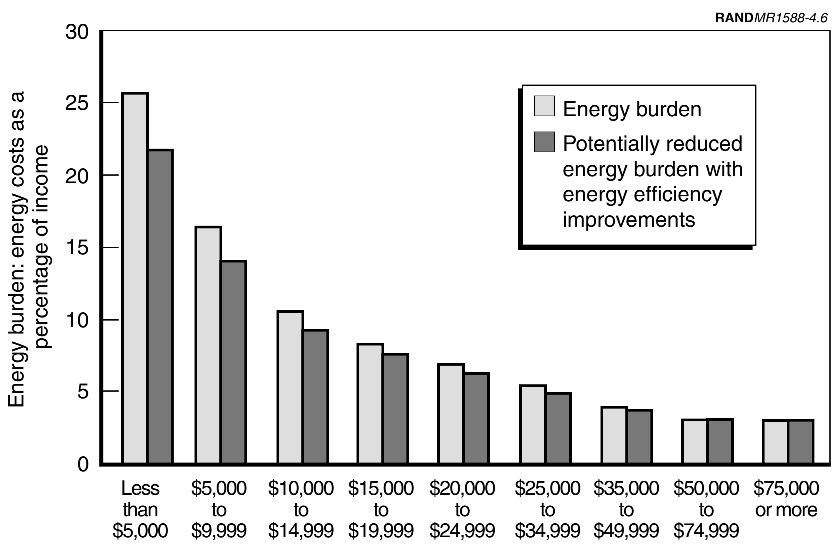
In recognition of these energy burdens, numerous federal, state, and utility administered programs have sought to reduce energy costs by direct financial assistance and through energy efficiency programs. The federal Weatherization Assistance Program (WAP) was established in 1974 under the Community Services Act to reduce the cost of heating and cooling by improving building energy efficiency.

[3] Weatherization includes weather stripping, caulking, installation of storm windows and doors, insulating attics, and retrofitting space and water heaters (Berry, Brown, and Kinney, 1997).



SOURCES: EIA, 1999b; Berry, Brown, and Kinney, 1997.

Figure 4.5—Massachusetts Household Energy Expenditure as a Percentage of Income



SOURCES: DOE, 1997; Berry, Brown, and Kinney, 1997.

Figure 4.6—Massachusetts Household Energy Expenditure as a Percentage of Income and Potential Reduction of Energy Burden with Energy Efficiency Improvements

A 1997 metaevaluation of numerous state weatherization programs under WAP showed that benefit-cost ratios increased on the order of 80 percent between 1989 and 1996, due to more complete audits and better and more effectively targeted improvements (Berry, Brown, and Kinney, 1997). Various perspectives of benefits were employed, from one-year savings on energy bills to 20-year returns on societal benefits. In 1996 the average benefit-cost ratio for first year energy savings was 1.79. In the study, all of Massachusetts was included in the "moderate" climate belt, although we have noted earlier that the climate differs between the eastern and western areas of the state. Table 4.2 shows the average percentage reductions in home energy costs for households in the moderate climate region after weatherization. Average benefit-to-cost ratios, depending on the perspective, were 1.2 to 2.7 in this region.

A detailed study of low-income weatherization programs nationwide found that, in general, the more that is invested in weatherizing a dwelling, the greater the savings (Berry and Brown, 1996). More importantly, savings were found to be linear with costs over the entire range of the data, with no evidence of diminishing returns.

Aside from weatherization, other low-income energy efficiency measures include installation of compact fluorescent lightbulbs, which use approximately 70 percent less energy than incandescent bulbs, and refrigerator replacement, which can lower electric bills by $500 to $1,000 over the unit's lifetime. The federal Low-Income Home Energy Assistance Program (LIHEAP), administered by the Department of Health and Human Services, was established in 1980 to reduce the burden of energy costs, to improve health, safety, and comfort, and to prevent termination of energy services. LIHEAP provides block grants to states and other administrative bodies, which in turn apply their own selection criteria within the federal guidelines.

Nationally, funding for LIHEAP declined from approximately $2.1 billion in 1985 to $900 million in 1996; perhaps not coincidentally, the number of service terminations has doubled since 1988 as well (Pye 1996). In response to recent price shocks, LIHEAP funding has increased to approximately $1.3 billion in 2001

Table 4.2

First-Year Reduction in Home Energy Costs

	Electricity		Natural Gas	
Climate	Space Heating	Total	Space Heating	Total
"Moderate"	44%	15%	18%	12%

SOURCE: Berry, Brown, and Kinney, 1997.

(NCAT, 2001a). Allocations to Massachusetts have increased from $44.9 million to $57 million in 2000 and 2001, with additional emergency funds of $50.1 million and $13.0 million made available in those same years (DHHS, 1999). In addition, supplementary funds of approximately $42 million were available to low-income residents in Massachusetts in 1999 and 2000 (NCAT, 2001b). Additional funding is anticipated to increase service to 123,000 households in the 2001 program year—still only approximately 17 percent of the eligible population. While a full cost-effectiveness analysis of low-income energy efficiency programs in Massachusetts is beyond the scope of this report, many of these types of programs nationwide have been shown to be cost-effective (Pye, 1996).

The more efficient the home, the less the expenditure on energy. In this respect, low-income households benefit from having more disposable income, as do all households. But low-income households derive a broader set of benefits from a reduced energy burden. These benefits include increased comfort and health, appliance safety, reduced loss of service from termination, and increased value to property owners. Some of the cost savings from energy efficiency may be reinvested in increased usage. For example, if a residence is better insulated so as to increase the energy efficiency of air conditioning, the household may spend the same amount as previously on air conditioning but have more comfort (Brown, Berry, and Kinney, 1994).

Benefits from greater energy efficiency for low-income households may go beyond the direct benefit to the households. These benefits may include reduced arrearages, increase in quality of housing, and possibly an improved local economy (Howat and Oppenheim, 1999).

5. Conclusions

Our analysis shows that reductions in energy intensity—controlled for exogenous factors like price, industrial mix, and capital expenditures—are associated with important economic and environmental benefits for Massachusetts and its citizens from 1977 to 1997. It is possible that these benefits can continue into the future. These benefits occurred in the presence of investment in energy efficiency programs by the government, the private sector, and state residents, but we have shown no specific link between mandated government or voluntary private energy efficiency programs and improvements in energy intensity in the state. Past evaluations of energy efficiency programs targeted at the commercial and industrial sectors, however, indicate that the programs can be directly responsible for energy savings. We have shown that claimed savings of commercial and industrial energy efficiency programs have provided a positive return on utility investment, assuming that this return has been revealed in our controlled analysis of changes in energy intensity, and that our limited data on utility investment and savings are indicative of the wider range of utility conservation programs. Future programs that have similar success rates as their predecessors would likely result in continued economic benefits to the state.

In addition, we have demonstrated benefits of energy efficiency for Massachusetts households—particularly for low-income households in eastern Massachusetts. Energy efficiency programs that focus on residential consumers can directly increase both net income and quality of life for those consumers.

The future of energy consumption, prices, and intensity remains uncertain. The analysis here suggests that greater energy efficiency has had, and may continue to have, a strong association with economic growth in Massachusettes. Together, targeted energy efficiency programs in commercial, industrial, and residential sectors have the potential to continue to provide benefits to the state and remain a cost-effective option for meeting the state's increasing energy demand. Specifically, how these various programs affect aggregate energy intensity remains a subject of further research.

Appendix

This appendix summarizes the quantitative results of our analysis of economic impacts of changes in commercial and industrial energy intensity. This study employs a methodology used in a previous RAND study that examined the public benefit of energy efficiency to the state of California (Bernstein et al., 2000). We refer the reader to that study for more detailed discussion of the theory behind the methodology.

Empirical Specification

We consider the following regression specification:

$$EI_{it} = \beta_1 P_{it}^{e} + \beta_2 EM_{it} + \beta_3 K_{it} + \beta_4 C_{it} + \lambda_i + \nu_t + \varepsilon_{it} \qquad (1)$$

where *i* indexes states, *t* indexes time, and the variables are all in log form and defined as follows:

EI — Energy intensity in the industrial sector taking the form E_{it}/Y_{it}, where E is energy consumption and Y represents industrial output (10^3 Btu/\$).[1]

P^e — Real energy prices in the industrial sector (\$/10^6 Btu).

EM — Proportion of industrial output accounted for by energy-intensive manufacturing. In the regression results below, nonmining manufacturing intensity (*Manufacturing*) and mining intensity (*Mining*) are allowed to have separate effects.[2]

K — New capital expenditures (buildings and equipment) in the industrial sector (\$$10^6$).

C — An index of heating and cooling days.

λ — A state fixed effect.

ν — A time fixed effect.

[1] All economic variables are deflated using the Producer Price Index for Finished Goods, with base year 1982.

[2] Energy-intensive manufacturing industries include mining (30000), stone, clay, and glass (51320), primary metals (51330), paper products (52260), chemicals (52280), and petroleum products (52290).

Our approach is to use energy intensity directly as a proxy for energy efficiency. To be concrete, consider the following model of gross state product (GSP):

$$\begin{aligned}\Delta_t \ln GSP_{it} = {} & \alpha_0 + \Delta_{t-1}\ln EI_i\alpha_1 + \Delta_{t-1}\ln P_i^e\alpha_2 + \Delta_{t-1}\ln EM_i\alpha_3 \\ & + \Delta_{t-1}\ln K_i\alpha_4 + \Delta_{t-1}\ln C_i\alpha_5 + \Delta_t \ln X_i\alpha_6 + \lambda_i + \nu_t + \varepsilon_{it}\end{aligned} \tag{2}$$

where Δ_t denotes first differences between periods *t* and *t – 1* (e.g., $\Delta_t \ln GSP_{it} = \ln GSP_{i,t} - \ln GSP_{i,t-1}$) and Δ_{t-1} denotes first differences between periods *t – 1* and *t – 2*. The variables in the model are defined as follows:

GSP Per capita gross state product ($\$10^6$).

EI A vector of energy intensity variables taking the form E_{ijt}/Y_{ijt}, where E_j represents the energy consumption in sector *j* (industrial, commercial, and transportation) in Btu and Y_j represents the output of that sector (10^3 Btu/\$).

P^e A vector of real energy prices in the industrial, commercial, and transportation sectors ($\$/10^6$).

EM Proportion of industrial output accounted for by energy-intensive manufacturing (*Manufacturing* and *Mining*).

K A vector of new capital expenditures in the industrial sector (*New capital*, $\$10^6$) and stock of commercial building square footage (*Building*, ft^2).

C An index of heating and cooling days.

X A vector of additional covariates typically included in cross-state growth regressions—proportion of the population of working age (18–65), proportion of the population with a college-level education or more, service share of output, and government expenditures as a fraction of total output.

λ A state fixed effect.

ν A time fixed effect.

This specification follows a large literature on the determinants of economic growth.[3] It argues that per capita state economic growth is correlated with both the stock and flow of capital and labor, their quality, and governmental policies. The inclusion of state fixed effects accounts for differences in initial economic

[3] Standard references include Solow (1957), Denison (1962), Barro and Sala-i-Martin (1995), Griliches (1998), and Jorgenson, Gollop, and Fraumeni (1987). See Crain and Lee (1999) for a review of the empirical literature on the determinants of U.S. state economic growth.

conditions and governmental policies (separate from expenditures) that affect economic growth. Time fixed effects control for business cycle effects common to all states.

Results

Table A.3 presents our baseline regression results of the effect of changes in the growth rate of industrial and commercial energy intensity (Table A.1) on state economic growth. The coefficients (shown in Table A.2) on industrial and commercial energy intensity (–0.023 and –0.017) indicate that GSP growth rises as state economies become less energy intensive. These estimates tells us that a 10 percent increase in the rate of growth in industrial energy intensity, for example, leads to a 0.23 percent decline in the rate of state economic growth. The remaining covariates in the model generally have signs and magnitudes consistent with the literature on state economic growth. One exception is the coefficient estimate on *new capital*. Investment is generally thought to be the cornerstone of economic growth, and so it is somewhat puzzling that *new capital* is statistically insignificant. This is at odds with the literature on economic growth in general, although the measurement of industrial capital is generally difficult and the particular measure used here is different from those employed in other studies of state economic growth.[4] Also, as noted above, the effect of any measurement error in this variable, which tends to bias the coefficient toward zero, will be exacerbated using first differences and state fixed effects. Note that the addition of new commercial buildings, a variable that is easier to quantify than industrial capital, has the expected sign and is of a substantial magnitude.

Although, at first glance, these coefficients appear small, their cumulative effects on the level of state GSP over time can be quite large because growth is an exponential process. Table A.4 illustrates the predicted effect of energy intensity on state economic growth using data on GSP and energy intensity averaged across the 48 states in our analysis. Three columns list the mean values of *Ind. EI*, *Com. EI*, and per capita GSP. The next column estimates what per capita income would have been had there been no change in energy intensity between 1979 and 1997.[5] Actual per capita GSP in 1997 was $22,363 (1982$).[6] Had there been no change in energy intensity, the model predicts per capita GSP in 1997 would

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[4]See, for example, Munnell (1990) and Holtz-Eakin (1993), who construct their own state series on capital accumulation.

[5]Because the data are first differenced and lagged one period, we lose two years of data.

[6]Except as otherwise noted, results are generally reported in real 1982 dollars (1982$) in this appendix; 1998 dollars (1998$) are reported in the body of this report.

have been $21,746. Thus, we can conclude that the decline in industrial and commercial energy intensity between 1979 and 1997 increased per capita income in 1997 by 2.84 percent, or $617 ($806 in 1998$). Considering the size of the U.S. population, by these estimates, the decline in energy intensity made a significant contribution to aggregate welfare over this period. Table A.4 also presents 95 percent confidence intervals around the predicted effect of energy intensity on GSP.[7] Note that this interval widens as we deviate further from the mean value of *Ind. EI* and *Com. EI* (27.56 and 5.28). In 1997, the 95 percent confidence interval lies between $797 and $816 (1998$).

Results for Massachusetts

The energy intensity coefficients estimated previously represent average effects over the 48 states in the analysis. It is entirely plausible that the effect of energy intensity on economic growth in Massachusetts deviates from this average. Unfortunately, we do not have sufficient data to produce these coefficients separately for Massachusetts. One approach, then, is simply to apply the energy intensity coefficients estimated for the entire sample to data from Massachusetts.

Table A.5 lists the mean values of *Ind. EI*, *Com. EI*, and per capita GSP for Massachusetts. As in Table A.4, the next column estimates what per capita income would have been had there been no change in energy intensity between 1977 and 1997, assuming energy intensity has the same effect in Massachusetts as it does on average in the other states in our sample. Actual per capita GSP in Massachusetts in 1997 was $27,727 (1982$). Had there been no change in energy intensity, the model predicts per capita GSP in 1997 would have been $26,454 (1982$). By this estimate, the decline in industrial and commercial energy intensity between 1977 and 1997 increased per capita income in 1997 in Massachusetts by 4.81 percent, or $1,273 ($1,664 in 1998$). Again, since the change in energy intensity in Massachusetts deviates from the average change in the entire sample used to calculate $\hat{\alpha}_1$, we generate 95 percent confidence intervals around the predicted effect of energy intensity on GSP as we did in Table A.4. These bounds are presented in the last two columns of Table A.5. These estimates imply that the decline in energy intensity in Massachusetts increased per capita income by between $1,657 and $1,669 in 1997 (1998$).

A second approach is to group states with similar characteristics together and estimate the model separately for each group. The coefficient estimates then

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[7] We approximate this interval as $\hat{y}_j \pm 2[\hat{\sigma}^2 X_j (X'X)^{-1} X_j']$.

presumably reflect the unique circumstances of those states. We experiment with three different categorizations that divide the sample into quartiles based on industrial intensity (i.e., percentage of GSP accounted for by industrial output), industrial energy prices, and climate. We also divide states into those with no, weak, and strong building codes and by DOE region (10 regions).[8] The trouble with this approach, of course, is that by dividing the sample into groups our coefficient estimates are derived from substantially smaller samples and so are generally less precisely estimated. Also, it is possible that by grouping states in one dimension, we may also group them by some other unknown dimension that could have unpredictable effects on the coefficient estimates.

Table A.6 presents the industrial and commercial energy intensity coefficients for the group of states in which Massachusetts falls for each of these five categorizations.[9] The only estimates that seem to tell a consistent story are those based on industrial intensity. We would expect that changes in industrial energy intensity would have less of an effect on GSP in states with relatively low industrial intensity. This is indeed what we see in the data. States in the first quartile of industrial intensity, like Massachusetts, have a relatively small and imprecisely estimated coefficient on *Ind. EI* and relatively large coefficient on *Com. EI*. This is reversed in states in the fourth quartile of industrial intensity (not shown)—they have a relatively large coefficient on *Ind. EI* and relatively small coefficient on *Com. EI*. The other categorizations do not yield any discernible pattern in the coefficient estimates.

Table A.7 assumes that the coefficient estimates generated by states in the first quartile of industrial intensity are representative of the effect of industrial and commercial energy intensity on GSP in Massachusetts. By these estimates, the decline in industrial and commercial energy intensity between 1977 and 1997 increased per capita income in 1997 in Massachusetts by 7.6 percent, or roughly $1,960 ($2,562 in 1998$). The 95 percent confidence interval for this estimate lies between $2,549 and $2,576 in 1997 (1998$).

The Value of Energy Intensity to the Massachusetts Economy

To estimate the value of improvements in energy intensity to the Massachusetts economy, we start with the expression used in the regression (2), rewritten as:

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[8]See Ortiz and Bernstein (1999) for a listing of states by type of building code.

[9]Massachusetts is in the first (i.e., lowest) quartile of states by industrial intensity and climate and the fourth quartile of states by industrial energy prices. Massachusetts is among states with strict building codes.

$$\Delta_t \ln GSP_t = \alpha_1' + \Delta_{t-1} \ln EI_{\text{ind}} \alpha_{\text{ind}} + \Delta_{t-1} \ln EI_{\text{comm}} \alpha_{\text{comm}}$$

where GSP_t is the gross state product, α_t' is the growth rate of state product in the year *t* due to all causes except changes in energy intensity, EI_{ind} and EI_{com} are the industrial and commercial energy intensities, respectively, and α_{ind} and α_{comm} are the coefficients relating changes in energy intensity to changes in the rate of growth of state product.

For the period 1977 to 1997, we have data on the gross state product and the industrial and commercial energy intensities. Using values of the coefficients α_{ind} and α_{comm} obtained from the regression analysis, we can calculate, α_t', the growth due to factors other than changes in energy intensity. We can then estimate what the state gross product would have been if energy intensity had not improved from 1977 through 1997, by writing

$$\Delta_t \ln GSP_t' = \alpha_t'$$

where the estimate of what gross product would have been without energy intensity improvements depends on our estimates of the impact of energy intensity, as represented by the coefficients α_{ind} and α_{comm}.

The value of the changes in energy intensity that did occur, measured in terms of impacts on state gross product, are thus given in each year *t* by

$$\text{Value of changes in energy intensity}_t = GSP_t - GSP_t'$$

This estimate depends on our estimates of the coefficients α_{ind} and α_{comm}. Since there is uncertainty in these estimates, we calculate a range of estimates for the value of changes in energy intensity corresponding to our range of estimates for the coefficients.

We can similarly estimate the value of improvements in energy intensity by making forecasts of future growth in gross state product and future trends in energy intensity. Forecasts of each of these factors are available from a variety of sources, but the one thing we know for certain about forecasts is that they are generally wrong. Rather than use a single forecast, we will thus use past trends to create an ensemble of forecasts and calculate the value of changes in energy intensity across this ensemble.[10]

[10] The American Heritage dictionary defines *ensemble* as a unit or group of complementary parts that contribute to a single effect. Our use of the term here is meant to signify that a single forecast is much less valuable than a range of scenarios employed toward a common purpose.

To calculate an ensemble of future growth rates of gross state product due to factors other than changes in energy intensity, we estimate future values of α'_t from its past trends. This growth rate has waxed and waned between 1977 and 1997, with recessions in the early 1980s and 1990s, interspersed with periods of rapid growth. We calculate high, low, and medium estimates for α'_t of 3.24 percent, 2.41 percent, and 1.17 percent by calculating the average growth rates over the periods 1985 to 1997, 1977 to 1997, and 1977 to 1985.

Similarly, we calculate an ensemble of scenarios of future trends in energy intensity, as shown in Figure 3.2, by projecting the average rate of change over observed from 1977 to 1997, 1977 to 1990, and offer that growth could reverse itself in years to come—perhaps not entirely, but perhaps at half the rate it grew from 1977 to 1997.

For each combination of forecasted energy intensity trends, state gross product due to factors other than changes in energy intensity, and estimates of the impacts of changes in energy intensity, we can then estimate the future value of the energy intensity using the same formula as we used to estimate the past value.

Tables and Figures

Table A.1

U.S. and Massachusetts Industrial and Commercial Energy Intensity (10^3 Btu/$1982): 1977–1997

	U.S.		Massachusetts	
Year	Ind.	Com.	Ind.	Com.
1977	30.78	5.84	13.51	6.73
1978	29.57	5.73	12.68	6.49
1979	30.59	5.79	10.96	5.58
1980	31.14	5.92	9.58	5.86
1981	28.97	5.83	10.52	5.28
1982	27.19	5.74	9.71	5.51
1983	26.90	5.36	9.65	4.51
1984	25.95	5.12	9.08	4.22
1985	24.80	4.74	8.58	3.89
1986	23.81	4.37	7.72	3.65
1987	23.82	4.28	7.07	3.41
1988	23.31	4.23	6.17	3.30
1989	24.01	4.22	6.90	3.50
1990	24.87	4.15	8.79	3.49
1991	25.67	4.09	8.59	3.60
1992	26.15	3.84	9.74	3.45
1993	25.66	3.80	10.62	3.24
1994	24.54	3.68	9.57	3.22
1995	24.16	3.68	10.06	3.12
1996	24.31	3.67	10.07	3.08
1997	23.32	3.55	9.61	2.99

Table A.2

The Determinants of Industrial and Commercial Energy Intensity

	Ind. EI		*Com. EI*	
	Coef.	Std. Err.	Coef.	Std. Err.
P^e	–0.687	0.085	–0.045	0.071
Manufacturing	0.276	0.041	—	—
Mining	0.060	0.170	—	—
New capital	–0.014	0.021	—	—
Building	—	—	–0.152	0.069
Climate	0.242	0.135	0.553	0.110
	Observations:	R-Squared:	Observations:	R-Squared:
	1008	0.933	1008	0.872

NOTES: All variables are in logs. Regressions include state and time fixed effects. Standard errors are corrected for heteroscedasticity.

Table A.3

The Effect of Energy Intensity on Per Capita State Economic Growth: 1977–1997

	Coef.	Std. Err.	95% Confidence Interval
Industrial Energy Intensity	–0.023	0.006	–0.036 to –0.011
Commercial Energy Intensity	–0.017	0.008	–0.032 to –0.002
Transportation Energy Intensity	0.003	0.011	–0.019 to 0.025
Industrial Energy Prices	–0.011	0.009	–0.027 to 0.006
Commercial Energy Prices	–0.034	0.008	–0.050 to –0.017
Transportation Energy Prices	–0.001	0.020	–0.041 to 0.039
Manufacturing GSP	–0.011	0.006	–0.022 to –6.7E–05
Percent of Industrial GSP from Mining	0.008	0.003	0.002 to 0.015
New Capital Expenditures	8.7E–07	4.1E–07	5.9E–08 to 1.7E–06
New Building Stock	0.186	0.066	0.057 to 0.315
Climate	0.013	0.009	–0.005 to 0.032
Population Age 18–64	1.123	0.156	0.816 to 1.430
Population Bachelors	–0.003	0.005	–0.014 to 0.007
Percent GSP from Government	–0.329	0.034	–0.396 to –0.263
Percent GSP from Service	–0.741	0.052	–0.844 to –0.638

NOTES: Observations: 912; R-Squared: 0.900. All variables, except *new capital* are in logged first differenced form. See text for variable definitions. Regression controls for state and year fixed effects. Standard errors are corrected for heteroscedasticity across panels.

Table A.4

Predicted Effect of Industrial and Commercial Energy Intensity on State Per Capita GSP: National Average, 1979–1997

Year	Δ_{t-1} ln *Ind. EI*	Δ_{t-1} ln *Com. EI*	Actual Per Capita *GSP*	State Per Capita GSP Given no Change in *Ind. EI* or *Com. EI*	Lower-Bound Effect	Upper-Bound Effect
1979	–0.065	–0.023	13,811	13,773	13,760	13,786
1980	0.029	0.003	13,200	13,103	13,097	13,108
1981	0.013	0.026	13,450	13,321	13,315	13,327
1982	–0.067	–0.034	13,299	13,162	13,148	13,175
1983	–0.023	0.007	13,794	13,685	13,681	13,689
1984	–0.006	–0.058	14,988	14,820	14,808	14,832
1985	–0.042	–0.024	15,721	15,502	15,492	15,512
1986	–0.025	–0.067	16,492	16,227	16,210	16,243
1987	–0.030	–0.077	17,186	16,843	16,823	16,863
1988	–0.011	–0.020	18,012	17,606	17,600	17,612
1989	–0.012	0.002	18,072	17,665	17,663	17,668
1990	0.023	–0.002	18,032	17,635	17,630	17,640
1991	0.021	–0.017	18,140	17,763	17,757	17,770
1992	0.032	–0.019	18,723	18,354	18,346	18,363
1993	0.022	–0.075	19,287	18,896	18,875	18,917
1994	–0.017	–0.010	20,279	19,847	19,842	19,852
1995	–0.053	–0.029	20,823	20,331	20,314	20,347
1996	–0.022	–0.013	21,271	20,733	20,726	20,740
1997	–0.021	0.018	22,363	21,746	21,738	21,753

NOTES: Estimates assume a constant marginal effect of *Ind. EI* of –0.022 and *Com. EI* of –0.045 on GSP growth. See text for derivation of lower- and upper-bound effects. All figures are in 1982$.

Table A.5

Predicted Effect of Industrial and Commercial Energy Intensity on Per Capita GSP: Massachusetts, 1979–1997

Year	Δ_{t-1} ln *Ind. EI*	Δ_{t-1} ln *Com. EI*	Actual Per Capita *GSP*	MA Per Capita GSP Given No Change in *Ind. EI* or *Com. EI*	Lower-Bound Effect	Upper-Bound Effect
1979	–0.063	–0.036	13,840	13,810	13,797	13,824
1980	–0.146	–0.150	13,500	13,384	13,343	13,426
1981	–0.135	0.049	13,701	13,552	13,527	13,577
1982	0.094	–0.104	14,152	13,996	13,970	14,022
1983	–0.080	0.042	15,427	15,187	15,171	15,204
1984	–0.006	–0.199	17,162	16,752	16,706	16,798
1985	–0.061	–0.067	18,695	18,143	18,121	18,165
1986	–0.057	–0.081	20,689	19,932	19,906	19,959
1987	–0.104	–0.064	22,305	21,360	21,326	21,394
1988	–0.089	–0.068	23,582	22,480	22,447	22,514
1989	–0.135	–0.032	23,287	22,114	22,073	22,155
1990	0.111	0.057	22,301	21,236	21,198	21,274
1991	0.242	–0.002	22,121	21,183	21,117	21,249
1992	–0.022	0.033	22,658	21,692	21,680	21,704
1993	0.125	–0.044	23,429	22,465	22,428	22,502
1994	0.086	–0.061	24,805	23,769	23,737	23,801
1995	–0.104	–0.009	25,421	24,291	24,258	24,323
1996	0.050	–0.031	26,235	25,072	25,053	25,091
1997	0.001	–0.011	27,727	26,454	26,450	26,459

NOTES: Baseline estimates assume a constant marginal effect of *Ind. EI* of –0.022 and *Com. EI* of –0.045 on GSP growth. See text for derivation of lower- and upper-bound effects. All figures are in 1982$.

Table A.6

The Effect of Industrial and Commercial Energy Intensity on Massachusetts's Rate of Economic Growth: Sensitivity Analysis

	Ind. EI		*Com. EI*	
Group	Coef.	Std. Err.	Coef.	Std. Err.
Low industrial intensity	–0.020	0.015	–0.054	0.019
Low industrial energy prices	–0.011	0.013	–0.026	0.016
Moderately severe climate	–0.028	0.010	–0.027	0.012
Strict building codes	–0.030	0.008	–0.024	0.008
DOE region	–0.008	0.013	–0.006	0.016

NOTES: Regressions control for all covariates listed in Table A.3. See text for explanation of groupings. Standard errors are corrected for heteroscedasticity across panels.

Table A.7

Predicted Effect of Industrial and Commercial Energy Intensity on Massachusetts 's Per Capita GSP: Alternative Coefficient Estimates

Year	Δ_{t-1} ln *Ind. EI*	Δ_{t-1} ln *Com. EI*	Actual Per Capita *GSP*	Per Capita GSP Given No Change in *Ind. EI* or *Com. EI*	Lower-Bound Effect	Upper-Bound Effect
1979	–0.063	–0.036	13,840	13,795	13,755	13,834
1980	–0.146	–0.150	13,500	13,300	13,179	13,420
1981	–0.135	0.049	13,701	13,495	13,447	13,544
1982	0.094	–0.104	14,152	13,883	13,833	13,932
1983	–0.080	0.042	15,427	15,089	15,058	15,120
1984	–0.006	–0.199	17,162	16,533	16,417	16,650
1985	–0.061	–0.067	18,695	17,868	17,805	17,931
1986	–0.057	–0.081	20,689	19,581	19,506	19,656
1987	–0.104	–0.064	22,305	20,944	20,849	21,039
1988	–0.089	–0.068	23,582	21,996	21,901	22,091
1989	–0.135	–0.032	23,287	21,621	21,516	21,726
1990	0.111	0.057	22,301	20,800	20,697	20,904
1991	0.242	–0.002	22,121	20,731	20,578	20,883
1992	–0.022	0.033	22,658	21,255	21,232	21,278
1993	0.125	–0.044	23,429	21,970	21,898	22,042
1994	0.086	–0.061	24,805	23,189	23,132	23,247
1995	–0.104	–0.009	25,421	23,699	23,621	23,776
1996	0.050	–0.031	26,235	24,430	24,396	24,464
1997	0.001	–0.011	27,727	25,767	25,756	25,777

NOTES: Baseline estimates assume a constant marginal effect of *Ind. EI* of –0.020 and *Com. EI* of –0.054 on GSP growth. See text for derivation of lower– and upper–bound effects. All figures are in 1982$.

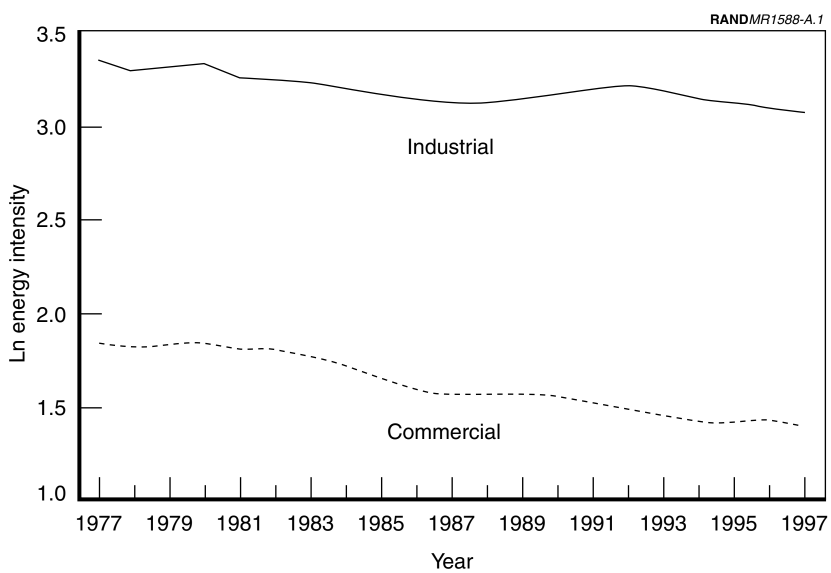

Figure A.1—U.S. Energy Intensity: 1977–1997

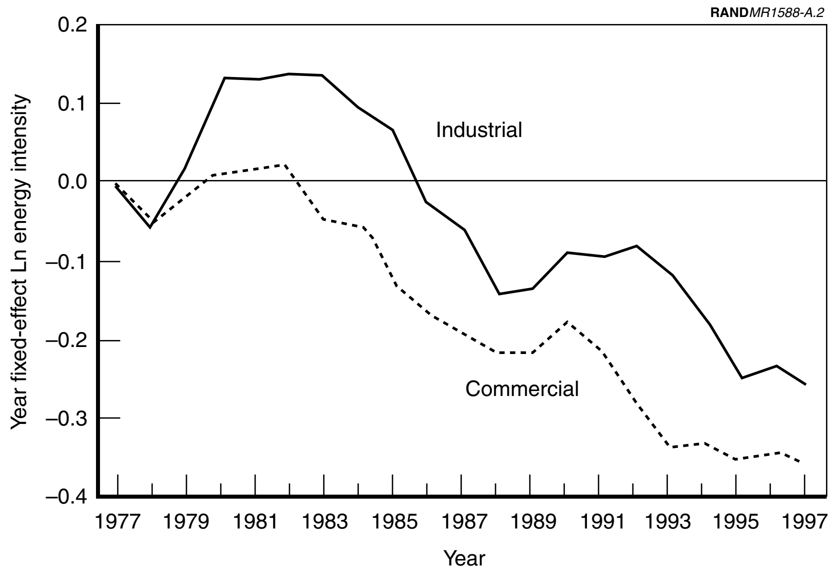

Figure A.2—U.S. Energy Intensity Fixed-Effect Coefficients Relative to 1977 Energy Intensity

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