An Economic Growth Model of Investment, Energy Savings, and CO2 Reductions: An Integrated Analysis of Policies that Increase Investments in Advanced Efficient/Low-Carbon Technologies

by

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ABSTRACT

A new analysis by the EPA Office of Atmospheric Programs and the Argonne National Laboratory (ANL), summarized briefly in this paper, indicates that a policy-driven, technology-led investment strategy can secure substantial domestic reductions of greenhouse gas emissions at a net positive impact on the U.S. economy. The analysis uses ANL’s All Modular Industry Growth Assessment (AMIGA) system to represent the effects of a successful expansion of a well-designed set of low-carbon policies and programs. The results from these numerical simulations show that investments in cost-effective technologies that are energy-efficient and/or low-carbon intensive will tend to increase overall economic activity within the United States. Moreover, the analysis reveals a small increase in the nation’s employment level. These positive results stem from: (i) a net reduction in energy expenditures made possible by investments that save money for businesses and consumers; and (ii) using revenues from the application of a carbon charge to reduce payroll taxes.

INTRODUCTION

In this paper we quantify some of the macroeconomic and sector-level benefits that can result from increased investments in energy-efficient and renewable energy technologies by the year 2020. Such investments are the result of programs and policies designed to overcome the many institutional and organizational barriers that slow the adoption of energy-efficient, low-carbon technologies. More specifically, the macroeconomic results are based on the Reference Case and Advanced Scenario (preliminary runs) specified in the DOE-sponsored study, Scenarios for a Clean Energy Future (Sept. 1999 draft). This new study follows earlier work prepared by several National Laboratories (Interlaboratory Working Group 1997).

For the analysis presented in this paper, we use the Argonne National Laboratory’s general equilibrium model, the All Modular Industry Growth Assessment (AMIGA) system, to represent the effects of a successful expansion of well-designed energy efficiency and renewable energy policies and programs (Hanson 1999). The results from numerical simulations show that investments in cost-effective energy efficiency
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technologies will tend to increase overall economic activity within the United States. Moreover, the analysis also reveals a small increase in the nation's employment level. This is especially true if the revenues collected from the issuance of carbon emission permits are used to reduce existing tax distortions such as the payroll tax (Benjamin 1998). These positive results stem from a net reduction in energy expenditures made possible by the investment in cost-effective energy efficient technologies.

OVERVIEW OF THE AMIGA SYSTEM

Over the last few years, a new economic impact modeling system, the All Modular Industry Growth Assessment (AMIGA) system, has been developed with the capability to represent many of the specific policy options for reducing carbon emissions. The system has household and government modules and three industrial production modules. In addition, the system has capital stock accumulation, depreciation and utilization modules including a light-duty vehicle stock module, and buildings and appliances stock modules. Stock characteristics include equipment vintage, energy efficiency, and operating costs in providing some capital or energy-related service. The modules include considerable technology, employment, and trade detail. The set of modules that make up the AMIGA system provide a comprehensive representation of the production sectors and absorption of goods and services in the U.S. economy. An aggregation module calculates various performance measures and macroeconomic concepts, such as national income and consumer price indices. The system is run annually, typically from year 2000 to 2020.

An important feature of the system is that the household demand module uses a household production function approach, based on the consumer demand theory of Kelvin Lancaster (1971). Consumer demand related to durable goods depends on the attributes of the services derived from the use of these goods, i.e., vehicles, housing, and appliances. Thus, if an attribute such as home heating comfort can be provided with less energy and at lower cost with improved technology, then the household would be financially better off. Some household income will become available to save or to spend on other goods and services. The functional forms used to specify demand are consistent with microeconomic theory and are structured hierarchically. As an example, transportation services can be met with different size vehicles that are not perfect substitutes. Resulting changes in consumer welfare from policies that promote the development and adoption of energy efficient technologies can be measured by equivalent variation, the change in income at which the representative consumer would have the same welfare. The demand functions are estimated using Department of Commerce National Income and Product Accounts (NIPA) time series data. The NIPA accounts provide annual data by detailed product categories. We make adjustments to impute the services derived from stocks of durable goods.

In all the modules, it is important to represent how purchased energy and capital can combine to provide energy-related services and to represent opportunities for pushing the technology and decision-making frontiers in these areas. Hence, specific models have been developed for energy-capital substitution opportunities and technology adoption for
major energy services. Trends in government spending are taken to be exogenous, except for programs related to climate policy and changes in energy demand due to the government’s own energy efficiency measures.

All the AMIGA modules are programmed in C-code. The AMIGA system operating shell controls the execution of all the modules. First, a preprocessor module sets up the base year databases for each module. A modified, enhanced Gauss-Seidel type algorithm is used to find a general equilibrium solution to the system of equations. After convergence, information can be accessed from any of the modules and output reports are prepared.

Associated with each activity are price and quantity indices, where expenditures equal price times quantity. Quantities are measured either in terms of real dollars or, where appropriate, in physical units. The AMIGA system passes price data into a module that purchases an external material and calculates the total quantity of intermediate demand. Total costs of producing each product are calculated. In equilibrium, supply and demand balance for each good or service.

For industrial sectors, a CES aggregator function is used to combine labor and capital services from producer durable equipment and structures, creating value added as the output. The standard theory of expenditure functions is used to obtain the derived demands for the factors of labor and capital. Investment demand is derived from demand for capital services.

Regarding international trade, some goods, such as crude oil, are considered perfect substitutes whether they are produced domestically or abroad. However, we make the Armington assumption that most final and semi-finished goods are differentiated, i.e., that these imports are close but not perfect substitutes for domestically produced goods. We use elasticity of substitution values based on the MIT Emission Prediction and Policy Analysis (EPPA) model (Yang, et al. 1996). Then demand for a sector’s product is interpreted as a demand for the aggregated combination of the domestic and imported goods. Again, the CES function is used as the aggregator. The elasticity of substitution is taken in most cases to be 0.7, somewhat less elastic than what is assumed in the MIT EPPA model, which uses a Cobb-Douglas (C-D) function as the aggregator for value added.

In terms of programming implementation, a module consists of one or more files containing C-code programs (or in older terminology, “subroutines”). Each module has at least one “header” file, which defines the names of variables and structural groups of variables, to be used within the module (but these variables are not accessible to other modules unless the two modules are explicitly linked). User control inputs may be attached as arguments to the execution command or read in from a user inputs control file in text data format. The module may also read in data tables from other text files to initialize its data base structures. The model has a flexible, user friendly interface.
There are hundreds of different materials, semi-finished goods, business services, and production processes modeled in AMIGA. Currently, we are taking the simple approach of using Leontief technologies regarding the demand for these intermediate inputs, but with the opportunity for time trends and with the introduction (and materials characterization) of future products, e.g., electric or hybrid vehicles. Hence, materials substitution occurs through the choice of substitute products with different materials composition.

Product outputs, material inputs, labor, capital, and energy are all related through production processes and technology. Expansion of labor input, investment, and technical advances drive economic growth over time.

The basic representation for the model of "ideal" factor demands is obtained from the following production structure: for each sector $i$:

$\text{Sector Output} = f^{\text{CES}}(\text{Utilized Capital, Labor Input})$

$\text{Utilized Capital} = f^{\text{LEON}}(\text{Production Capital, Energy Services})$

$\text{Energy Services}_j = f^{C-D}_j(\text{Energy-Saving Capital, Energy Input})$

where $\text{Energy Services}$ can be provided by multiple energy forms, denoted by $j$.

The sector output function, above, is given by a constant elasticity of substitution (CES) functional form, with industry-specific substitution elasticities obtained from estimates in the literature (Varian 1992). Services from utilized capital are represented by a quantity index number calibrated to the base year (1992), with the price index normalized to one in the base year. This index number includes both capital rental plus energy services, where energy services themselves are given by combining energy-saving capital with energy input. The equation above for $\text{Utilized Capital}$ can be taken in the long run to be Leontief, since the capital-energy substitution possibilities are captured in the third equation. However, over the business cycle, there may be periods in which demand for output decreases and then typically the ratio, $\text{Energy Services} / \text{Utilized Capital}$, increases. (We are currently not including this effect because our reference forecast is one of smooth economic growth.). The management of energy flows to a process is slightly sensitive to the price of energy; short-run price elasticities of energy demand between 0.1 to 0.15 are used.

The C-D energy service equation is adapted from the 18-sector LIEF model (Ross 1993). These equations are specific to the sector and energy form (electricity and fossil fuels). Side conditions are used to account for combined heat and power (cogeneration) systems. Some electricity can be self-generated by using by-product fuels or purchased natural gas. Also, some of the heat demands otherwise supplied by gas-fired furnaces can be met from the waste heat from cogeneration systems.
The production model shown above combined with technology penetration equations gives rise to investment demands. Investment spending is a component of GDP. This model is sensitive to energy prices and to information and voluntary agreement programs. The latter are represented by increased penetration rates for energy-efficient capital and/or by reduced hurdle rates, which reflect the higher priority being attached to energy management. The programs are win-win opportunities, since the voluntary agreements encourage adoption of cost effective measures.

As we said earlier, the model uses a household production function approach to represent consumer energy demand. This is analogous to using industry production functions (Lancaster 1971). Household transportation services are "produced" using vehicle capital stocks and fuel. Energy-related housing services such as heating, cooling, and hot water are also viewed as being produced by the household. When the technology used to provide energy-related services improves (e.g., more efficient electric heat pumps or vehicles with greater fuel economy in miles per gallon), then these household services can be provided with less energy and possibly at lower life-cycle costs.

TECHNOLOGY-LED EMISSION REDUCTIONS

To determine the macroeconomic impacts of energy-related greenhouse gas emissions reductions supported by smart technology policies, the analysis discussed here is driven by preliminary estimates of technology resource potentials in the study, *Scenarios for a Clean Energy Future* (Interlaboratory Working Group, 1999 draft). The results are similar to studies done elsewhere. See, especially, Alliance to Save Energy, *et al.*, 1997; Koomey, *et al.* 1998; Laitner 1997; Laitner, *et al.* 1999; and World Wildlife Fund 1999. As in the other studies, this analysis uses an integrating framework of a macroeconomic model (in this case, the AMIGA modeling system) to assess supply and demand interactions, capital stock turnover, and the larger impacts on the U.S. economy.
Table 1. Energy and Carbon Savings in an Advanced Efficiency/Low Carbon Scenario (Compared to the Reference Case Scenario for the Year 2010)

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Total Primary Energy Consumption (Quads)</td>
<td>11.32</td>
</tr>
<tr>
<td>Electricity Sales (billion kWh)</td>
<td>380</td>
</tr>
<tr>
<td>Carbon Emission Reductions (MtC)</td>
<td></td>
</tr>
<tr>
<td>Buildings and Industry Direct Fuel Use (MtC)</td>
<td>59.4</td>
</tr>
<tr>
<td>Transportation (MtC)</td>
<td>61.5</td>
</tr>
<tr>
<td>Electric Utilities (MtC)</td>
<td>180.3</td>
</tr>
<tr>
<td>Total Emission Reductions (MtC)</td>
<td>301.2</td>
</tr>
</tbody>
</table>

Incorporating a set of sector-specific, cost-effective policies and technologies that drive an advanced efficiency/low carbon (AELC) scenario, and assuming a $50 per ton carbon charge, AMIGA estimates a total carbon reduction of 301 million metric tons of carbon (MtC) by the year 2010. This is summarized in Table 1, above. The AELC scenario reduces the forecasted carbon emissions from 1805 to 1504 MtC by 2010. Assuming a 7 percent below 1990 level to comply with the Kyoto protocol — in effect, lowering U.S. domestic emissions to about 1252 MtC in 2010 — the domestic mitigation strategies outlined in the Clean Energy Future would provide the United States with about 54 percent of its needed energy-related carbon reductions. Of this amount, about 180 MtC (or 60 percent) is achieved through improvements in electricity supply and end-use efficiencies in the buildings and industrial sectors. Another 62 MtC (20 percent) in reductions are achieved through improvements in transportation efficiencies. The balance of the reductions, 59 MtC (20 percent), is achieved through improvements in direct fuel efficiencies in buildings and industrial end-uses.

Decreases in end-use electricity demand drive about one-third of the electricity-related carbon reductions, 65 MtC (36 percent) by 2010. The AMIGA simulations indicate that cost-effective reductions in electricity use will reduce consumption from 3,612 to 3,232 billion kWh. The balance of the carbon reductions in the electricity sector, 115 MtC (64 percent), is achieved from the use of more efficient electricity generation, fuel switching, and renewable energy resources.

IMPACT ON ECONOMIC ACTIVITY

Table 2, below, shows the results of simulating the effects of a bundle of energy efficiency policies, programs, and incentives. Incremental investments are shown as totals and are broken down for buildings, industry, and motor vehicles. Two features about the incremental investment paths are important. First, the programs grow over time, with the amount of private sector investment initially at about $0.36 billion in year 2000, growing to about $34.16 billion in 2010, to about $37.38 billion in 2020 (all in 1992 dollars). Second, there is a tendency to select the least-cost measures (with the highest rates of return) first. By taking the opportunities with the highest payoffs early, a substantial savings on energy bills is realized within the first few years. This savings in energy expenditures from the initial energy efficiency investments is available to reinvest in additional energy efficiency measures, basically leading to “internal financing”
of future measures for many firms. Finally, the revenues generated from a $50 per tonne carbon charge are used to support R&D programs as well as a variety of other policies designed to accelerate investment in energy-efficient, low-carbon technologies. The level of program and R&D spending rises from $0.61 billion in 2000 to $14.82 billion by 2020. As we also shall see later in this paper, remaining revenues from the carbon charge are used to reduce payroll taxes to partially offset the slightly higher energy prices that result from the carbon charge.

Table 2. Incremental Investment in Energy Efficiency Measures and the Resulting Savings in Energy Expenditures (billion 1992 $)

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
</tr>
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<tbody>
<tr>
<td>Residential incremental efficiency investment</td>
<td>-0.15</td>
<td>7.38</td>
<td>8.13</td>
</tr>
<tr>
<td>Commercial incremental efficiency investment</td>
<td>-0.11</td>
<td>5.52</td>
<td>6.09</td>
</tr>
<tr>
<td>Industrial incremental efficiency investment</td>
<td>0.03</td>
<td>4.17</td>
<td>4.18</td>
</tr>
<tr>
<td>Motor vehicles incremental efficiency investment</td>
<td>0.59</td>
<td>17.09</td>
<td>18.98</td>
</tr>
<tr>
<td>Total incremental efficiency investment</td>
<td>0.36</td>
<td>34.16</td>
<td>37.38</td>
</tr>
<tr>
<td>Total program and R&amp;D expenditures</td>
<td>0.61</td>
<td>8.39</td>
<td>14.82</td>
</tr>
<tr>
<td>Total savings in energy expenditures</td>
<td>2.22</td>
<td>17.46</td>
<td>127.68</td>
</tr>
<tr>
<td>Net energy-related savings</td>
<td>1.25</td>
<td>-25.09</td>
<td>75.48</td>
</tr>
</tbody>
</table>

Table 2 finally shows the total reduction in energy expenditures that grow from a relatively small savings of $2.22 billion in the year 2000, the first simulation year, to a $17.46 billion savings in 2010 and a $127.68 billion savings in 2020. The net energy-related savings in a given year are calculated as the total energy savings less total incremental investment and program expenditures in that year.

In the very first year the net energy-related savings are small but positive. As the level of program spending and private investment accelerates through 2010, the net energy savings are negative since the energy savings haven’t grown sufficiently large to offset the direct costs. However, the net savings in energy expenditures become quite large, reaching $17.46 billion in 2010 and $127.68 billion in 2020. Hence, the net savings are positive shortly after 2010, reaching $75.48 billion by 2020.

Note that although Table 2 stops in year 2020, much of the reduction in carbon emissions and savings in physical energy and associated energy bills will occur after 2020. This is the result of investments in energy efficient capital being put into place prior to 2020. The fact that current energy savings depend on cumulative past investments ultimately leads to extraordinary growth in energy savings over time.
Table 3. Macroeconomic Impacts of a High Efficiency/Low Carbon Scenario
(Compared to the Baseline Scenario for Various Years)

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Domestic Product</td>
<td>0.9</td>
<td>32.9</td>
<td>72.2</td>
</tr>
<tr>
<td>(millions of 1992 dollars)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Household Consumption</td>
<td>-1.5</td>
<td>4.3</td>
<td>30.2</td>
</tr>
<tr>
<td>(millions of 1992 dollars)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investment</td>
<td>3.6</td>
<td>26.5</td>
<td>25.8</td>
</tr>
<tr>
<td>(millions of 1992 dollars)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Employment</td>
<td>0.0</td>
<td>100.0</td>
<td>70.0</td>
</tr>
<tr>
<td>(thousands of net jobs)</td>
<td></td>
<td></td>
<td></td>
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</table>

Table 3, above, summarizes the key macroeconomic impacts of the AELC scenario compared to the reference case analysis. These are described more fully in the paragraphs that follow.

Gross Domestic Product

Overall efficiency improvements in the economy imply that more goods and services can be produced from the labor and other resources that are available. The growth path in incremental GDP (i.e., changes from a business-as-usual scenario) closely follows the growth path in total energy expenditure savings shown in Table 2. There is an economic rationale for this close relationship. The energy expenditures represent the economic value (at least approximately) of the inputs used to produce energy. Hence, the reduction in energy expenditures approximates the opportunity cost of the input factors that are freed up to produce other goods and services. This relationship is only approximate because of differing sectoral factor intensities and adjustment costs. In 2010 the net impact on GDP is $32.9 billion, rising to $72.2 billion by 2020. This amounts to an increase of about 0.3 percent and 0.6 percent in years 2010 and 2020, respectively. This is relative to the GDP value projected in the business-as-usual scenario of the Reference Case Scenario of the Clean Energy Future.

GDP is not a strict welfare concept; rather, it is a measure of the total value of output of the goods and services produced within a country. Output includes investment goods produced as well as consumption goods and services. Therefore, the incremental investment in energy efficiency measures adds to the investment component of GDP. This means that the net energy-related savings shown in the last line of Table 2 will translate approximately into increases in consumption, or additional savings.

Household Consumption and Savings

The net energy-related savings shown in Table 2 does not translate into household consumption increases as a fixed share over time because households tend to borrow to smooth out their consumption paths (or add to their wealth if they receive a transient increase in income). A vast amount of theoretical and empirical literature supports this smoothing behavior (Merton 1992). In the year 2000, household consumption decreases only slightly as a consequence of the negative net energy-related savings in that year. Thereafter, the increase in consumption grows rapidly, but not as fast as the net energy-related savings grows because of the consumption smoothing effect. Soon the first-year...
borrowing by households is paid back, and after that, some of the net energy-related savings go into increases in accumulated wealth (Shell 1969).

The Capital Stock

The incremental investments in energy-efficient and renewable energy capital add to the nation’s total capital stock. The composition of the capital stock also changes somewhat. There is less investment in conventional energy supply capacity, which represents intended commitments to produce more energy in the future. But there is more investment in "clean energy supply technologies" such as combined cycle natural gas generation units, combined heat and power systems, and renewable energy technologies. There is also more investment in energy efficient buildings, appliances, vehicles, and industrial processes. Without these incremental investments in energy efficiency, there would be less efficient buildings, appliances, vehicles, and industrial processes that would require increased future streams of energy production. Investments in energy efficiency promote energy security and hedge against situations of higher energy prices in the future.

Sector Output and Employment

The output and employment in most sectors tend to increase as a result of a more efficient economy. There are direct new business opportunities for those sectors involved in supplying the energy efficient investment goods, including construction (both new and retrofitting), motor vehicles, commercial and household appliances, lighting, HVAC systems, and industrial equipment. These business opportunities more than offset the lost output from lower production and distribution of fossil fuels that produce carbon dioxide as well as other pollutants.

The estimates of economic benefits provided here are underestimated in the sense that attendant co-benefits from adopting energy efficient technologies are not yet included (Mills and Rosenfeld, 1994). For example, improved lighting and HVAC systems increase comfort in houses and increase worker productivity in businesses, yet these benefits are not accounted for with the standard accounting framework of policy models. Yet, technologies that are adopted are evaluated on the basis of many different attributes. The probability is that at least several characteristics of the adopted technology are improvements over previously available models. One type of investment that yields particularly high economic gains is one that improves process throughput within an existing industrial facility. In Lawrence Berkeley National Laboratory’s work with process industries, a number of these technology opportunities have been identified, especially in the heavy industries. See, especially, Ruth, et al, 1999. More broadly, a recent analysis has indicated that including energy savings alone do not account for the full economic returns to industry when evaluating energy efficiency improvements. (Laitner and Finman 1999; Elliott, et al. 1997).
REFERENCES


**KEY WORDS**

Energy Efficiency, Investments, Macroeconomics, Economic Growth, Energy Modeling, Climate Change