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Energy-Economy Interactions Revisited Within a Comprehensive Sectoral Model

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ABSTRACT

This paper describes a computable general equilibrium (CGE) model with considerable sector and technology detail, the *All Modular Industry Growth Assessment* Model (AMIGA). It is argued that a detailed model is important to capture and understand the several roles that energy plays within the economy. Fundamental consumer and industrial demands are for the services from energy; hence, energy demand is a derived demand based on the need for heating, cooling, mechanical, electrical, and transportation services. Technologies that provide energy-services more efficiently (on a life cycle basis), when adopted, result in increased future output of the economy and higher paths of household consumption. The AMIGA model can examine the effects on energy use and economic output of increases in energy prices (e.g., a carbon charge) and other incentive-based policies or energy-efficiency programs.

Energy sectors and sub-sector activities included in the model involve energy extraction, conversion, and transportation. There are business opportunities to produce energy-efficient goods (i.e., appliances, control systems, buildings, automobiles, clean electricity). These activities are represented in the model by characterizing their likely production processes (e.g., lighter weight motor vehicles). Also, multiple industrial processes can produce the same output but with different technologies and inputs. Secondary recovery, i.e., recycling processes, are examples of these multiple processes. Combined heat and power (CHP) is also represented for energy-intensive industries. Other modules represent residential and commercial building technologies to supply energy services. All sectors of the economy command real resources (capital services and labor).

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Key Words: Energy Modeling, Energy Efficiency, Macroeconomics, Investment

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DESCRIPTION OF THE MODELING SYSTEM

In this paper we briefly describe the AMIGA modeling system and discuss typical results applied to technology policy and climate policy. In the modeling system, supply and demand balances are calculated for all represented goods and services. This includes the supply and demand balance for energy-intensive and energy-related services, such as home heating and cooling and personal transportation.

The modeling system provides a consistent framework in which to embed technologies. In terms of economic concepts, a technology specifies the input intensity combinations that are available to produce a good or service as an output. There may also be joint outputs such as air pollution or greenhouse gases. The system is coded in C language. The lists of inputs used by each technology are set up as linked lists which point to the inputs and their prices.

Household demand equations are specified in terms of fundamental demands for final goods and services where some of the services are produced by the household itself (i.e., the household production function concept, see Kelvin Lancaster [1]). Technical advance in the provision of these services will lower the derived demand for purchased inputs, freeing up factors of production and increasing potential real output.

From a practical modeling perspective, there are two production cases that are sufficiently different to distinguish between.

1. Processes that produce intermediate or final goods or marketed services and use a variety of material and service inputs, as well as capital, labor, and energy-related services (such as demand for hot water).
2. The supply of energy-related services (such as supplying hot water) which use fuels or electricity in combination with energy-related capital and operating labor.

Regarding the first case above, the AMIGA model shows detail for about 200 production sectors. This allows for analysis using a distribution of parameters that characterize different sectors and allows for compositional effects (structural change) such as high-tech trends in the "new" economy.

We can also examine in which sectors adjustment costs may arise, e.g., coal mining in a low carbon scenario without sequestration, and perhaps even incorporate within a scenario specification, some offsetting mitigation measures where unusually large adjustment costs are deemed likely.

Regarding the second case above, whole modules of the modeling system specialize in representing the supply of energy services to various types of residential and commercial buildings, personal transportation, and industrial production. For example, the motor vehicle stock model supplies personal transportation services and contains vehicles of several size classes, so consumers can switch among vehicle sizes as a response to carbon charges or other incentives. We can then examine the effects on overall transportation fuel demand due to size switching and the attendant change in personal transportation services that households consume. There are real savings for the economy by reducing oil imports.

The detailed technology and sector representation allows the examination of market niches, such as opportunities for combined heat and power (CHP) in hospitals. The amount of energy-related service demand in a sector or building type limits the reduction in electricity and gas consumption achievable through energy-efficiency measures targeted at that market niche. By estimating the capital costs of these measures, we also derive the investment expenditures arising from energy efficiency measures. Investment flows are accounted for as putty-clay. The stock modules remember factor intensities such as fuel economy of vehicles by vintage.

Nested CES production structures are used to calculate factor intensities and dual output prices similar to the MIT EPPA model [2]. Further disaggregation of the industrial energy demand structure and parameter values are based on the LIEF model [3]. Investment flows for energy efficiency in industry are also modeled as putty-clay. The industrial energy demand modules remember energy factor intensities by vintage.

The detailed technology and sector representation also provides places to put the elements in a technology characterization. For example, advanced vehicle manufacturing may involve more aluminum intensive manufacturing processes. Different processes are included in the model to manufacture automobile bodies from aluminum rather than from conventional stamped steel. In fact, an advanced product may be manufactured in stages with each stage different than for the corresponding conventional product. This requires adding several sector production processes to the model that represent re-characterizations of material and service input intensities, such as auto body stamping.

Production activities are organized into three separate production modules. Although this configuration involves some duplication of computer code, this organization facilitates the specification and addition of particular re-characterized future sectors, augmenting conventional sectors. There may be more than one production process for a given good (e.g., different sources of electricity). Computer code that sets up particular types of production processes, including some re-characterized future sectors, is contained in only one of the production modules, whichever one is appropriate. We describe these three main production modules as follows:

"P" -- Process kinds of manufacturing, agriculture and mining;
"K" -- Construction and manufacturing of capital goods;
"S" -- Services.

The capital goods production module, "K," includes the construction of residential housing, commercial buildings, industrial structures and other facilities. It also includes the manufacture of durable equipment: metal fabrication, machines manufacturing, electric and electronic apparatus assembly. Where the details of a specific production process are important (e.g., electricity generation), sub-modules are created under one of the three main production modules.

Total electricity demands are passed to the electricity supply module. The electricity supply module contains approximately twenty types of electric generation technologies. Hydroelectric capacity and other renewable technologies are exogenous in the forecast. Fossil-fuel new capacity additions are calculated by using investment rules. Retirements are part of the scenario specification, but these can be made generally consistent with economic incentives, such as carbon charges. Lower electricity demand results in real resource savings. Lower demand saves fuel purchases by electric generators, operating and maintenance costs, and capital investments in new capacity.

The modeling system handles multiple regions by indexing the regional data, such as residential buildings, commercial buildings, and industry energy demand. C allows a flexible indexing system so that the modeling system can be automatically configured to accept alternative definitions of regions. Generic "utility" functions programmed in C can be used anywhere within the modeling system. For example, factor intensities and dual output prices derived from CES production functions are calculated in a generic "utility" function program call.

A preprocessor system is used to estimate the historical inputs of semi-finished goods, raw materials, purchased services, and energy-related services to produce a given good or service. The preprocessor writes several files that are read as standard inputs by the AMIGA modeling system. These input files specify the lists of production sectors and demand sectors.

The six distribution, or "markup," sectors in the modeling system are rail freight, trucking, water shipping, air freight, wholesale distribution, and retailing. Most transactions, e.g. a firm or household purchasing a material or finished good, are associated or bundled with distribution markup activities. The distribution sectors are assumed to be perfectly competitive industries so the sector outputs are driven by the demands for these distribution activities summed over all transactions in the economy. The end-use prices the households, firms, and governments pay are the sum of factory gate prices plus distribution markup cost margins. Household modal split for personal transportation is part of the specification and estimation of the household demand equations.

A hierarchical Gauss-Seidel algorithm is used to achieve convergence using three nested loops as follows:

- Outer convergence loop -- overall macroeconomic convergence path.
- Middle convergence loop -- capital spending to replace depreciated capital stocks and to increment net stocks and production capacities. Also balance labor market supply and with demand.
- Inner convergence loops -- sector outputs in the quantity portion of the system and dual prices for goods and services in the expenditure and price portion of the system. Calculate labor demands and demand for specific imported goods.

TYPICAL RESULTS

The modeling system can be run to simulate the effects of carbon charges and of R&D and other technology enhancing programs (e.g., Energy Star programs). The latter make new technologies available and promote their diffusion by lowering the effective hurdle rates for adoption. Technology policies and programs can help overcome market and organizational failures (imperfections) arising from principal-agent relationships in organizations and differences between social and private risk exposure. For example, the common separation between commercial building owners and managers is often attributed to reducing the incentive for undertaking energy-efficiency measures.

Up to a point, technology programs result in an increase in potential GDP with the impact rising over time as the advanced technologies diffuse. Real consumption also grows faster after a short, small initial reduction needed to finance the start of the investment stream in energy efficiency measures.

We include in the scenarios government program expenditures and the private R&D expenditures. We also model the electric third-party service sector -- within the overall electricity sector some jobs shift from building and operating new power plants to implementing energy-efficiency measures and devoting more effort to the efficient operation of equipment and systems.

Typical simulation results from representing a preliminary Clean Energy Future (CEF) advanced low-carbon scenario [4] are shown below in Tables 1 and 2.

Table 1. Energy and Carbon Savings in an Advanced Efficiency/Low Carbon Scenario (Compared to the Reference Case Scenario for the Year 2010)

Total Primary Energy Consumption (Quads)	11.32
Electricity Sales (billion kWh)	380
Carbon Emission Reductions (MtC)	
Buildings and Industry Direct Fuel Use (MtC)	59.4
Transportation (MtC)	61.5
Electric Utilities (MtC)	180.3
Total Emission Reductions (MtC)	301.2

Table 2. Macroeconomic Impacts of a High Efficiency/Low Carbon Scenario (Compared to the Baseline Scenario for Various Years)

	2000	2010	2020
Gross Domestic Product (millions of 1992 dollars)	0.9	32.9	72.2
Household Consumption (millions of 1992 dollars)	-1.5	4.3	30.2
Investment (millions of 1992 dollars)	3.6	26.5	25.8
Employment (thousands of net jobs)	0.0	100.0	70.0

The benefits of the policies and programs grow roughly exponentially over time as energy savings increase from the accumulated stock of more energy-efficient buildings, equipment, and vehicles.

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