Chapter 1. The Intertemporal General Equilibrium Model (IGEM)

1.1 Introduction

Intertemporal general equilibrium models represent worthwhile additions to the portfolio of methodologies for evaluating the benefits and costs of future policies. An intertemporal price system balances the demands and supplies for products and factors of production at each point in time. The forward-looking features of this system are the aggregate behavioral allocations of consumer full wealth across time and the linkage of asset prices to the present values of future capital services. These combine with backward linkages among current capital services, the stock of capital, and past investments in modeling the long-run dynamics of economic growth.

While models representing the intertemporal price system are essential for understanding the dynamics that underlie intermediate- and long-run growth trends, econometric implementation is equally critical to informing the design and review of public policy. Indeed, the overwhelming advantage of the econometric approach is that the responses of producers and consumers to changes in energy, environmental, trade and tax policies are derived from the wealth of historical experience that has accumulated over the past several decades.

It is important to recognize at the outset that the dominant tradition in general equilibrium modeling is not based on econometric methods. Instead, the models are calibrated to data from a social accounting matrix (SAM) and a relatively small number of parameters is selected from literature reviews. While calibration economizes on the use of data, it imposes severe restrictions on the unknown parameters describing technology and preferences. This approach is not feasible for IGEM, which represents technologies for 35 individual industries and preferences for hundreds of households.

IGEM remains unique among computable general equilibrium models as an empirically based model of the growth and structure of the U.S. economy. It preserves all the features of aggregate growth models while allowing detailed disaggregations of policy impacts. The econometric methods for modeling technology and preferences build on a system of national accounts that successfully integrates capital accounts with income and production accounts. The new accounting system incorporates an accumulation equation relating capital to past investments with an asset-pricing equation linking the price of assets to future prices and rates of return. The data base also pools aggregate time series on consumer behavior with cross-section data for individual households.

Developing and advancing IGEM requires ongoing innovations in econometric methodology and new methods for data construction. The innovations in econometrics include the development of new techniques for estimation and inference, as well as new approaches for representing technology and preferences as the basic building blocks of the model. The new methods for data construction require the solution of long-standing problems in national accounting in order to integrate income and product accounts with the accounts for capital and those for differentiated consumers. The evolution of IGEM was and is about process – from theory to observation through data, from data to model through estimation and from model to understanding through application.

For thirty-five years, the Intertemporal General Equilibrium Model has been applied to public policy in matters relating to energy, the environment and the economy. In the late 1970's and 1980's, analyses centered on oil and gas pricing policies, econometric and process model integrations and demand- and supply-side technology assessments. The concerns here were the economic consequences of oil and gas price decontrol and the efficacy of energy conservation, renewables and liquid and other supply alternatives in achieving meaningful petroleum import reductions (Jorgenson, 1998a).

In the 1990's, applications of IGEM shifted to the externalities associated with energy production and use. This began with an analysis of the economic costs of the Clean Air Act of 1970 (Jorgenson et al., 1993) followed by a series of analyses focused on social cost energy pricing and U.S. tax reform (Jorgenson et al., 1996, 1998). Finally, the applications focused on issues related to climate change and climate change policy (Jorgenson, 1997 and 1998b).

In the current decade, applications have been directed exclusively to examinations of the costs and benefits of climate change and climate change policy. In addition to continuing benefit assessments (Jorgenson, et al., 2004), we explored the role of substitution in climate change policy (Jorgenson, et al., 2000). We also conducted simulations for the Pew Center on Global Climate Change of the Climate Stewardship Acts of 2003 and 2004 (S.139, S.A.2028 and H.R.4067) and for the U.S. Environmental

Protection Agency of the Climate Stewardship and Innovation Act of 2007 (S.280), the Low Carbon Economy Act of 2007 (S.1766), the Lieberman-Warner Climate Security Acts of 2008 (S.2191 and its successor, S.3036), and the American Clean Energy and Security Act of 2009 (Waxman-Markey draft, H.R. 2454 and Senate Finance Committee versions) – (Jorgenson et al., 2008 and www.epa.gov/climatechange/economics/economicanalyses.html).

Our purpose in creating this volume is to provide a timely, unified, and comprehensive reference for IGEM. In Part 2, we present the technical details of the model, complete with its formal equations and discussions of data construction and econometric estimation. Part 1 is descriptive and focuses on model use, applications, outcomes and related special topics.

Chapter 2 covers model and parameter data sources, presents an illustrative base case and discusses base case calibrations. Chapter 3 presents our detailed analysis of the Clean Air Act of 1970. Chapter 4 focuses on marginal abatement costs for greenhouse gas emissions as a preamble to Chapter 5's analysis of a prototypical climate change policy, vintage 2003-2004. Chapters 6, 7 and 8 discuss important empirical issues that routinely surface in general equilibrium analyses of climate policy. These include the role of induced technical change (Chapter 6), the magnitude of the consumption-leisure tradeoff and the elasticity of labor supply (Chapter 7) and the relative rankings of revenue recycling mechanisms (Chapter 8). Finally, Chapter 9 presents an abstract for a forthcoming analysis of a yet-to-be-determined climate change initiative that employs the newest version of IGEM with a household model that incorporates labor-leisure choice into its representation of aggregate consumer behavior and with its restoration of measures of individual welfare that now depends on leisure as well as goods and services.

1.2 An overview of the Intertemporal General Equilibrium Model

The Intertemporal General Equilibrium Model or IGEM is a multi-sector, multi-period model of the U.S. economy. It is one of a class of models called computable general equilibrium (CGE) models because it solves for the market-clearing prices and quantities of each sector and market in each time period. The parameters (or coefficients) of the equations in IGEM are estimated econometrically from historical data spanning 40 to 50 years. The model consists of 35 producing sectors, the household or consumer sector, a household and business investment sector, the federal, state and local governments sector, and a foreign sector.

In IGEM, production is disaggregated into 35 separate industries producing one or more of 35 commodities. IGEM's industries and commodities are enumerated in Table 1.1 and generally match the two-digit sectors in the Standard Industrial Classification (SIC). Each industry or producing sector produces one primary product and may produce one or more additional goods or services. Each producing sector is modeled by a set of equations that fully represent possible substitutions among its inputs or factors—i.e., capital, labor, non-competing imports, and the 35 commodities.

Within each producing sector, changes in input demand (i.e., substitutions) occur because relative prices change, encouraging more or less use of that input. In addition, historical data invariably reveal trends (or biases) in input demands that are independent of input prices. This means there is either increasing or decreasing input usage over time, even after accounting for the changes arising from relative price incentives. For example, historical data may indicate that particular industries are increasingly labor-saving, energy-saving, or capital-using over time, independent of relative prices. The equations used to model production in IGEM account for both price- and trend-related substitution effects. Industry-level productivity growth also is part of the specification for each of the 35 producing sectors estimated econometrically from observed changes in input prices and observed technological trends.

These equations, along with others in the model, are organized in a variable coefficient, inter-industry input-output framework in which the demands for and supplies of each commodity, as well as those of capital and labor, must balance both in quantity and value (i.e., price times quantity). The organization of the "make" and annual "use" tables is illustrated in Figure 1.1. These are matrices at the industry and commodity level of detail. The cells in each use table depict commodity purchases (the rows) by each industry and final demand (the columns). The cells in each make table show the commodities produced by each industry. Figure 1.1 also shows the inputs of capital and labor into each producing and consuming sector.

Figure 1.2 depicts production and supply. Inputs of the 35 commodities plus capital, labor and non-competing imports are combined to produce domestic industrial outputs. In turn, these outputs are mapped into domestic commodity outputs through the use and make tables. Combining the domestic commodities with competitive foreign imports gives rise to the available supplies, which are purchased as intermediate inputs or finished goods (final demand).

The model is solved iteratively until the prices of all commodities and inputs are such that demand equals supply in all product and factor (input) markets. Model solutions depict, among other things, all prices and quantities, the complete structure of inputs to production, and industry-level rates of technological change. As a result, economy-wide changes in energy or capital intensity, for example, are calculated by adding up industry-level details.

Household consumption by commodity is the result of a three-stage, multi-period decision process (see Figure 1.3) involving price and demand equations like those of the producing sectors. First, households decide their levels of “full consumption” over time. Full consumption, comprising goods, services *and* leisure, is the amount of full wealth “consumed” in each period and is dependent on relative prices, current and future, and on the time path of interest rates (both of which are known to households with perfect foresight). Full wealth is the (present) value of household capital wealth (private, government and foreign) and the household time endowment.

The household time endowment is a population-based, monetary estimate of the amount of time available to the working-age population (those 14 through 74 years old) for work and leisure. It assumes that there are 14 hours per day of discretionary time for work and leisure with appropriate allowances for weekends, holidays and hours spent in school. The time endowment is evaluated at the prevailing wage or after-tax rate of labor compensation, including benefits and is adjusted for quality (i.e., educational attainment and experience). Leisure is defined as the uncompensated use of time (i.e., that portion of the 14 hours that people use for activities other than paid work).

Once households decide each period's full consumption, they then decide the split between the consumption of goods and services and the demand for leisure. This decision is based on the price of consumption relative to the wage rate (the opportunity cost, or price of leisure). When households decide their leisure demand, they simultaneously determine their labor supply and, so too, their labor income. Finally, households choose the allocation of total consumption among capital and the various categories of goods and services. Like production, these stages of household behavior are estimated econometrically from historical data, and the equations capture both price- and income-driven changes in observed spending patterns.

In the model, capital accumulation is the outcome of a series of decisions over time by households and firms. Households and businesses determine the amount of saving available in each period as the difference between their income and expenditures. Households and firms invest until the returns on additional investment are no longer greater than the cost of new capital goods. Capital is assumed to be perfectly mobile across households and corporate and non-corporate enterprises; in other words, capital flows to where it is demanded. Investment is structured according to an econometrically estimated model allowing substitutions among different types of capital goods. The total supply of capital at any time is fixed by the accumulated investment in these capital goods.

Government purchases are calculated to balance the available government revenues and a predetermined budget deficit. Government revenues arise by applying tax rates, both historical and projected, to the levels of income and wealth generated by the model. The composition of nominal government spending – for example, spending on automobiles, computers, highways, schools, and employees – is fixed by assumption.

Finally, the international exchange rate of the dollar against other currencies adjusts to bring net exports (exports less imports) into line with a predetermined trade balance in goods and services. This means that net foreign saving is insensitive to changes in U.S. prices and interest rates. Imports are considered imperfect substitutes for similar domestic commodities and compete on price, which in turn depends on the value of the relevant foreign currency. Export demands depend on assumed foreign incomes and the foreign prices of U.S. exports, which, in turn, are determined by domestic prices and the exchange rate.

In policy simulations, the assumptions regarding the budget and trade deficits drive important aspects of the process of capital formation. In combination, they imply that no “crowding-out” of private investment occurs as a result of changes in investment by either the government or foreign sectors. Holding the budget and trade deficits constant across simulations means that neither governments nor foreigners influence the level of investment spending beyond what is assumed for the base case. As a result, investment changes from one simulation to another depend entirely on changes in saving by households and businesses.

On the supply side, overall economic growth in IGEM, as in the real world, arises from three sources. These are productivity, accumulated capital, and the availability of labor. The model itself determines two of these – productivity and capital. Productivity depends on emerging trends in relative prices combined with the continuation of observed technological trends and patterns of innovation. Capital accumulation occurs as a result of the saving and investment behavior of producers and consumers. Labor supply is determined as households allocate their discretionary time between work and leisure. All of these, therefore, are products of the model.

U.S. population growth by age, race, sex, and educational attainment is projected to a zero-growth steady state using demographic assumptions consistent with U.S. Bureau of the Census forecasts; once in steady state, population is held constant. As indicated above, the population projection is used to calculate a projection of the economy's “time endowment” in dollar terms by applying historical wage patterns to estimates of the working-age population. Since the model largely determines productivity and capital accumulation, these population projections effectively determine the size of the economy in the distant future.

Models are necessarily an abstraction of the environment they portray, and IGEM is no exception. In characterizing the results from this methodology, three features merit consideration. Two of these are assumptions, while the third derives from the source of the model’s parameters. First, as indicated above, consumers in IGEM are assumed to have perfect foresight and are able to react today to expected future price changes. This means that they behave according to so-called “rational expectations.” There are no surprises in the form of price shocks. Since producers and consumers immediately plan for and adopt new (but not identifiable) “technologies,” there are no losses associated with equipment becoming prematurely obsolete or misaligned when technology or relative prices change repeatedly.

Second, labor and capital services (and the corresponding stock of capital goods) are assumed to be perfectly mobile among industries, households, and governments. This implies that labor and capital can migrate from sector to sector with little or no adjustment cost. Moreover, there are no capacity shortages or supply-demand imbalances associated with these migrations. Instead, persons, equipment and structures are effortlessly transformed into alternative occupations and uses.

Third, the model parameters in IGEM are based on 40 to 50 years of historical data. Much has changed in this span and these parameters reflect and embody these changes. Hence, model adjustments and reactions to changing economic conditions are based on observed long-term trends and their continuation with any short-run constraints on or lags in adjustment behavior also part of this history and these adjustments.

Taken together, these features imply that IGEM is more likely than other models are to produce “best” case outcomes (least losses or greatest gains) when confronted with significant economic changes. Households are fully aware of these changes through perfect foresight, substitution possibilities are long-run in nature and occur quickly and easily, and labor and capital readily migrate and mutate to new uses. Conversely, myopia, inflexibility in production and consumption, and low capital stock turnover are conditions that lead to “worst” case outcomes (greatest losses or least gains). In comparing model estimates of the economy’s response to environmental policies, those from IGEM will appear less damaging (or, more beneficial) than those from models in which there are more rigidities or higher adjustment costs.

Table 1.1: Definitions of IGEM's Industries and Commodities

Number	Description	Output	Value Added	1987 SIC No.
1	Agriculture, forestry and fisheries	424,010	183,644	01-02, 07-09
2	Metal mining	25,023	9,321	10
3	Coal mining	25,507	14,327	11-12
4	Crude petroleum and natural gas extraction	259,579	183,150	13
5	Non-metallic mineral mining	23,515	13,135	14
6	Construction	1,355,663	583,024	15-17
7	Food and kindred products	595,414	194,698	20
8	Tobacco manufactures	30,995	8,487	21
9	Textile mill products	60,180	21,741	22
10	Apparel and other textile products	35,993	15,043	23
11	Lumber and wood products	129,542	48,186	24
12	Furniture and fixtures	101,267	45,432	25
13	Paper and allied products	168,010	72,473	26
14	Printing and publishing	229,739	142,274	27
15	Chemicals and allied products	521,438	232,551	28
16	Petroleum refining	418,828	137,062	29
17	Rubber and plastic products	187,904	84,627	30
18	Leather and leather products	6,347	2,322	31
19	Stone, clay and glass products	129,354	63,015	32
20	Primary metals	251,132	77,017	33
21	Fabricated metal products	296,458	128,915	34
22	Non-electrical machinery	424,034	184,227	35
23	Electrical machinery	330,537	154,024	36
24	Motor vehicles	442,156	86,181	371
25	Other transportation equipment	227,460	112,275	372-379
26	Instruments	207,399	119,511	38
27	Miscellaneous manufacturing	60,531	25,679	39
28	Transportation and warehousing	667,845	312,326	40-47
29	Communications	527,862	292,268	48
30	Electric utilities	372,987	242,751	491, %493
31	Gas utilities	77,393	22,971	492, %493,
32	Wholesale and retail trade	2,487,860	1,512,276	50-59
33	Finance, insurance and real estate	2,752,265	1,790,676	60-67
34	Other personal and business services	4,353,650	2,797,203	70-87, 494-495
35	Government enterprises	327,507	215,913	

Notes: Figures are for 2005 in millions of dollars. % indicates part of an SIC code.

Figure 1.1: Organization of IGEM's Use and Make Tables

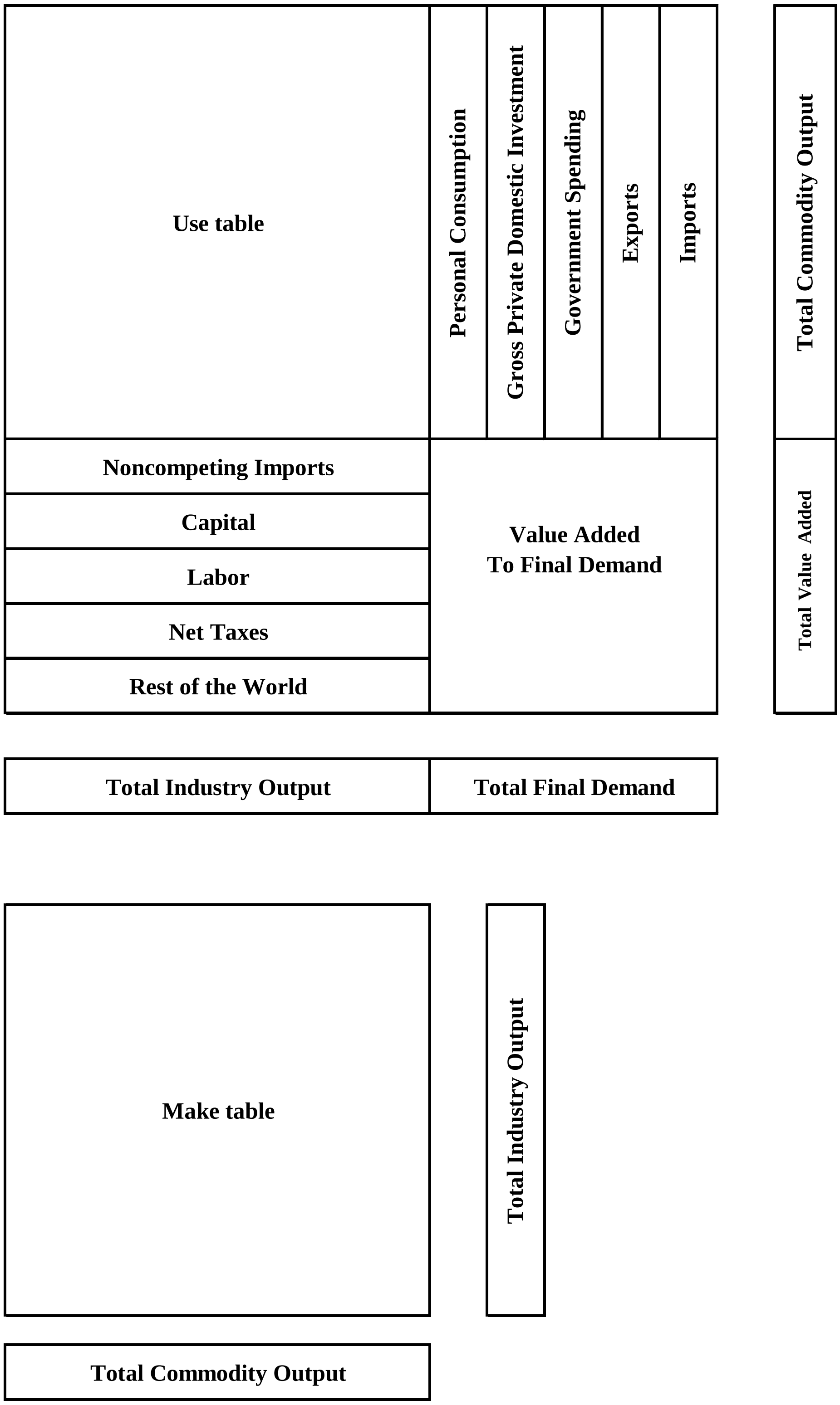

Figure 1.2: IGEM's Flows of Production and Commodity Supply

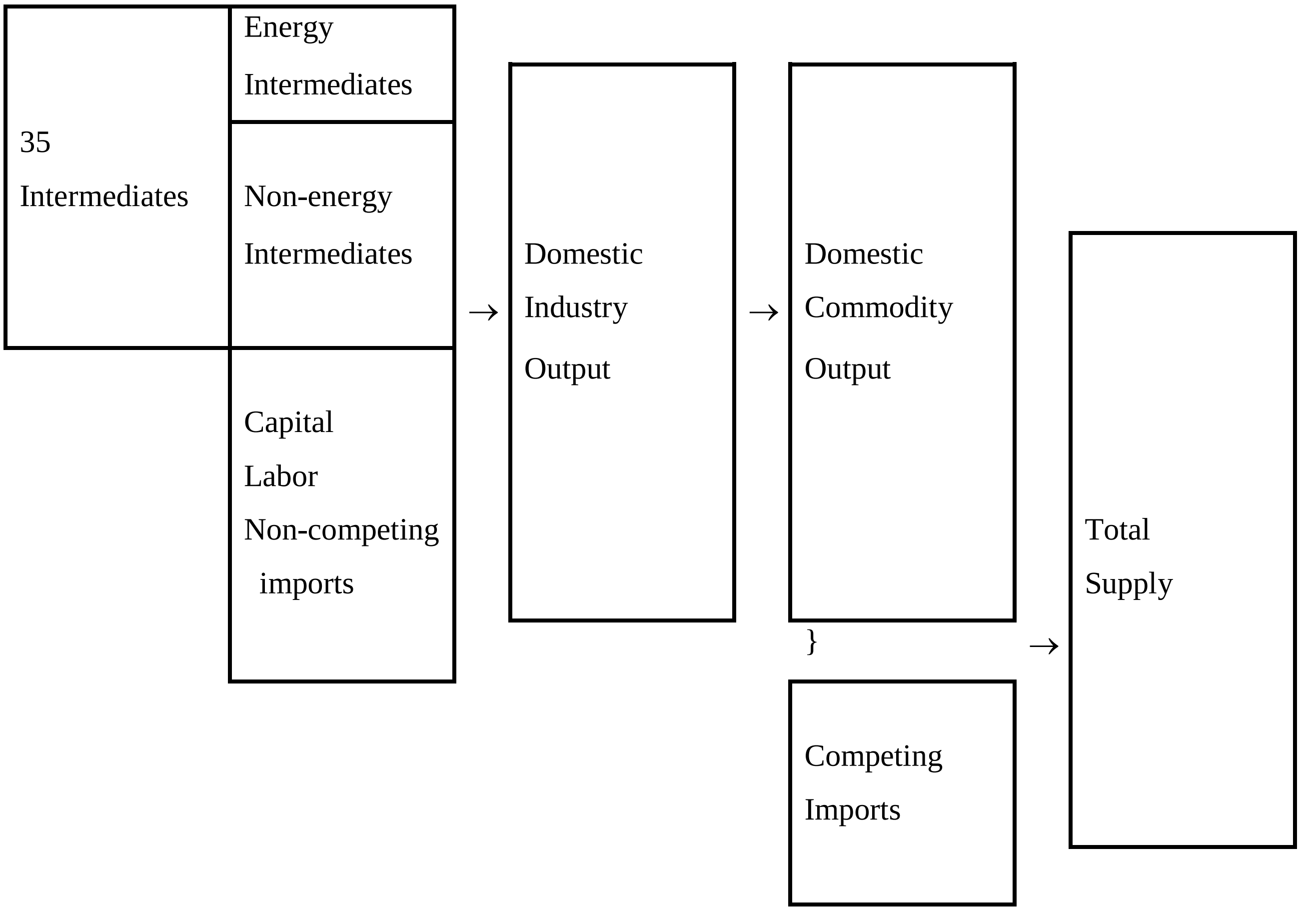

Figure 1.3: IGEM's Flow Representation of Household Behavior