Construction of an Athena-Like Economics Model

Irregular Warfare Modeling & Simulation Summit
17 – 19 May 2011

Jet Propulsion Laboratory
California Institute of Technology

Topics

• Athena-like models
  - Single-user simulation of consequences of long-term S&RO operations
  - Athena models focus on physical effects, political control, information, intelligence, civilian attitudes, demographics, and ... economics

• Why a computable general equilibrium (CGE) model is at the focal point of the economics model

• Recipe for an Athena-like economic model
  - Isolate the CGE part of the economic model
  - How to derive the CGE equations
  - Sector examples: Competitive producers, black markets, the populace, sectors without products (regional political actors, rest of region, rest of world)
What is a CGE?

- A CGE is a set of simultaneous non-linear equations that describe all the flows of value between sectors in an economy
  - Usually, money flows in one direction, goods & services in the other
  - A few equations describe how the economy works together to determine prices and quantities
  - Many of the equations describe how each participant chooses to use its income
  - One equation determines how much a dollar (rupee, etc.) is worth

- A CGE contains a lot of assumptions
  - What is exogenous (input) and what is endogenous (computed)?
  - Character of the economy — free markets? price controls? quotas?
  - How participants make decisions — maximize profit? maximize utility?
  - Production technology — e.g., how substitutable are inputs?
Does Credibility *Require* a CGE model?

• CGE methodology has been developing since 1960

• “CGE models today are routinely used by governments in policy formulation and debate”
  - IFPRI has published a template, with computer code in GAMS

• CGEs can use “social accounting matrix” (SAM) data to get parameter values that fit a real country
Why use a CGE instead of a DSGE?

• Dynamic stochastic general equilibrium (DSGE) models
  ✷ DSGE research is a hot topic among theoretical economists
  ✷ Basic idea: Participants make decisions on uncertain expectations
  ✷ Immense data requirements: Time series of social accounting matrices
    ➢ Works well in a stable society with unchanging policy variables
    ➢ Effects of changes in policy variables must be modeled
    ➢ But decision makers (producers and consumers) won’t rely on trends in chaos

• Computable general equilibrium (CGE) models
  ✷ Have a good track record and are still the primary choice for actual use
  ✷ Athena’s sector models respond to stimuli from demographic, political, military, and information models (and vice versa)
  ✷ In a broken economy, today’s data in a CGE may produce a *better* prediction of tomorrow than an extrapolation of past data in a DSGE
  ✷ Distinguishing *shape* and *size* parameters (discussed later) may make data from similar countries and recent times relevant
“Equilibrium”?!  

• First: Interpret value flows as rates, not annual amounts  

• Second: Only prices, production rates, jobs reach equilibrium  

• Third: All slow or delayed phenomena are outside the CGE  
  ✴ Ground model: production capacity, feedstocks, inventories, ..  
  ✴ Demographics: available labor force, number of consumers, insurgent recruitment, urban drift, effects of neighborhood security, wages, …  
  ✴ Politics: tax rates, baksheesh, political actors’ spending profiles, …  
  ✴ Attitudes: neighborhood security, …  
  ✴ Information: mitigation and tweaks to any of the above, …
Using a CGE in an Athena-Like Model

• Make a second pass through the CGE for latent demands

• Rest of simulation controls how CGE operates

• Honor the “laugh test”
  ✧ Producers maximize profit, but profit is zero — NO GOOD!
  ✧ Labor supply = labor demand, so unemployment is zero — NO GOOD!
Usable Data

• Data availability will always be an issue because past changes are a fact of life and future changes are an objective in an S&RO environment
  ✷ Historical SAM data has questionable applicability
  ✷ The shape vs. size distinction should allow use of data from nearby regions and recent times

• Shape and size parameters
  ✷ Shape: Relative expenditures, mostly driven by technology in use
  ✷ Size: Total expenditures, mostly driven by demographic changes and the scenario design
Recipe for an Athena-Like CGE

• Isolate the CGE and select sectors of interest
  ✷ KISS, but include sectors needed for all relevant issues
    ➢ Black markets — Yes, but prices are not competitively determined
    ➢ Subsistence agriculture — No, deal with that in demographics
  ✷ Increase resolution later by splitting sectors & reassessing equations

• Economy-wide equations
  ✷ Total demand for each sector’s product or factor of production is the sum of amounts demanded by all sectors
  ✷ Product prices drive quantities demanded and quantities produced
  ✷ CPI defines the value of a dollar (as gold = $35/oz did during 1946–1971)
  ✷ Available labor (and other factor quantities) are exogenous
    ➢ Actual amount used (e.g., the number of people working) is the smaller of supply and demand
Recipe — Sector-By-Sector Equations

• **Revenues**
  - Identify all sources of revenue
  - But compute the total revenue by summing payments to the sector

• **Costs**
  - Budgets must balance unless the sector supplies or absorbs money
  - Expenditures describe the aggregate behavior of the sector
    - Include savings, taxes, tax-like payments, normal profits, “net revenues”
    - Behavior
      - Do producers choose inputs that maximize profit?
      - Do consumers choose purchases that maximize utility?
      - Some sectors’ behavior may be outside the scope of the CGE

• **Net revenues**
  - Net revenues are the difference between Revenues and Costs
  - Competitive markets drive this “excess profit” to zero in equilibrium
Example — *goods*, A Competitive Producer

• Revenues can be expressed two ways
  ◦ Sum over sectors of *product price* times *sector demand*
  ◦ *Product price* times the *quantity produced*
  ◦ Thus, *sector demand* equals *quantity produced* (at equilibrium)

• Behavior
  ◦ Produce just enough quantity to match demand (no wasted output)
  ◦ Buy just enough of every input to make the output (no wasted inputs)
    - Technology of production is described by a production function, which describes relationships between input amounts and prices (thus, prices)

• Costs
  ◦ Pay for all inputs at their endogenously determined prices
  ◦ Pay taxes and make tax-like payments to *actors*, *region*, and *world*

• Net revenues
  ◦ Since normal profits are treated as a cost, net revenues are zero
Example — *black*, A Black Market

• **Revenues, as with *goods*,**
  - Sum of *price* times *demand* equals *price* times *production*
  - But black market prices are driven by exogenous world markets

• **Behavior**
  - Produce just enough to match demand
    - Unless limited by capacity or by the supply of feedstock
  - Buy inputs efficiently, which is described by a production function

• **Costs**
  - Pay for imported feedstock and all other inputs
  - Make tax-like payments (mostly bribes and baksheesh, I presume)

• **Net revenues**
  - Net Revenues (economists’ “profit”) is Revenues minus Costs
  - The black market is a major source of income for some political actors
Example — *pop*, The Populace

- **Revenues**
  - Payments for labor (and other factors of production if modeled)
    - The number of jobs is the sum of sector demands for labor
  - Also, government transfers, remittances, foreign aid, NGO aid
    - Exogenous

- **Behavior**
  - The demographics model determines the size of the labor force
  - Consumption choices spend all after-tax income to maximize “utility”

- **Costs**
  - Pay for consumption (based on number of consumers, not workers)
  - Pay taxes and make tax-like payments on wages, not total revenues

- **Subsistence agriculture**
  - Usually omitted from Gross Domestic Product calculations
  - Value the work of people engaged in subsistence agriculture at the wage associated with the poverty line
Example — *actors*, Regional Political Actors

- **Revenues are the sum of all payments to *actors***
  - Net revenues from the black market
  - Earnings from some sectors, perhaps
  - Tax-like payments
  - Government stipends, perhaps

- **Behavior is modeled in the political model**
  - Actors attempt to achieve their goals by selecting tactics
  - Tactics can include accumulating money
  - Actors’ choices of tactics are constrained by money & other assets

- **Costs**
  - When the actors have selected tactics, their expenditures are summed in the political model and reported to the CGE

- **Net revenues**
  - Since the political model tracks actors’ asset levels, the *actors’* net revenues may often be non-zero in the short term
Example — *region*, The Rest of the Region

- **Revenues**
  - Supplies production capacity to the *black* and *goods* sectors, collecting tax-like payments in return
  - Collects tax-like payments from the workers in *pop*
  - Receives that part of foreign aid that does not get passed on to *pop*

- **Behavior**
  - Not modeled; assumed to be described by an editable budget

- **Costs**
  - All revenues are distributed according to the budget percentages

- **Net revenues**
  - Zero; deficit spending may be allowed in some later version
Example — *world*, The Rest of the World

- **Revenues**
  - Supplies imported feedstock to *black*
  - Collects taxes or tax-like payments from other sectors

- **Behavior**
  - Not modeled; assumed to be described by an editable budget
  - Cash flows that do not involve any sectors in the region are ignored
    - E.g., Foreign actors’ troops’ paychecks are outside the scope of the model

- **Costs**
  - Buys exogenous amounts of exports from *black, goods, pop*
  - Passes part of exogenous foreign aid to *region*
  - Gives exogenous government transfers, remittances, part of foreign aid, NGO aid to *pop*

- **Net revenues**
  - The rest of the world may be a net source or sink of money
Summary

• Credibility may require use of a CGE in the economic model
• Simulate slow and delayed phenomena outside the CGE
• Distinguishing shape and size parameters makes data usable
• A CGE is a set of simultaneous non-linear equations in P & Q
  ✤ Total quantity demanded for each output = sum of sector demands
  ✤ Q supplied (prices) = Q demanded (prices) or min( that, capacity )
  ✤ Set the value of a dollar from a base case or otherwise (numeraire)
  ✤ Sector spending behavior is modeled, most spend all their revenues
    ➢ Models describe assumed behavior under constraints (optimal?)
  ✤ Run the CGE with & without production constraints to get shortages
  ✤ Parameters and inventories are modeled elsewhere in the simulation
  ✤ Increase resolution by splitting sectors and re-deriving equations