Reflecting Bottom-up Technology in a CGE Model Framework:

Application of AMIGA Model in China

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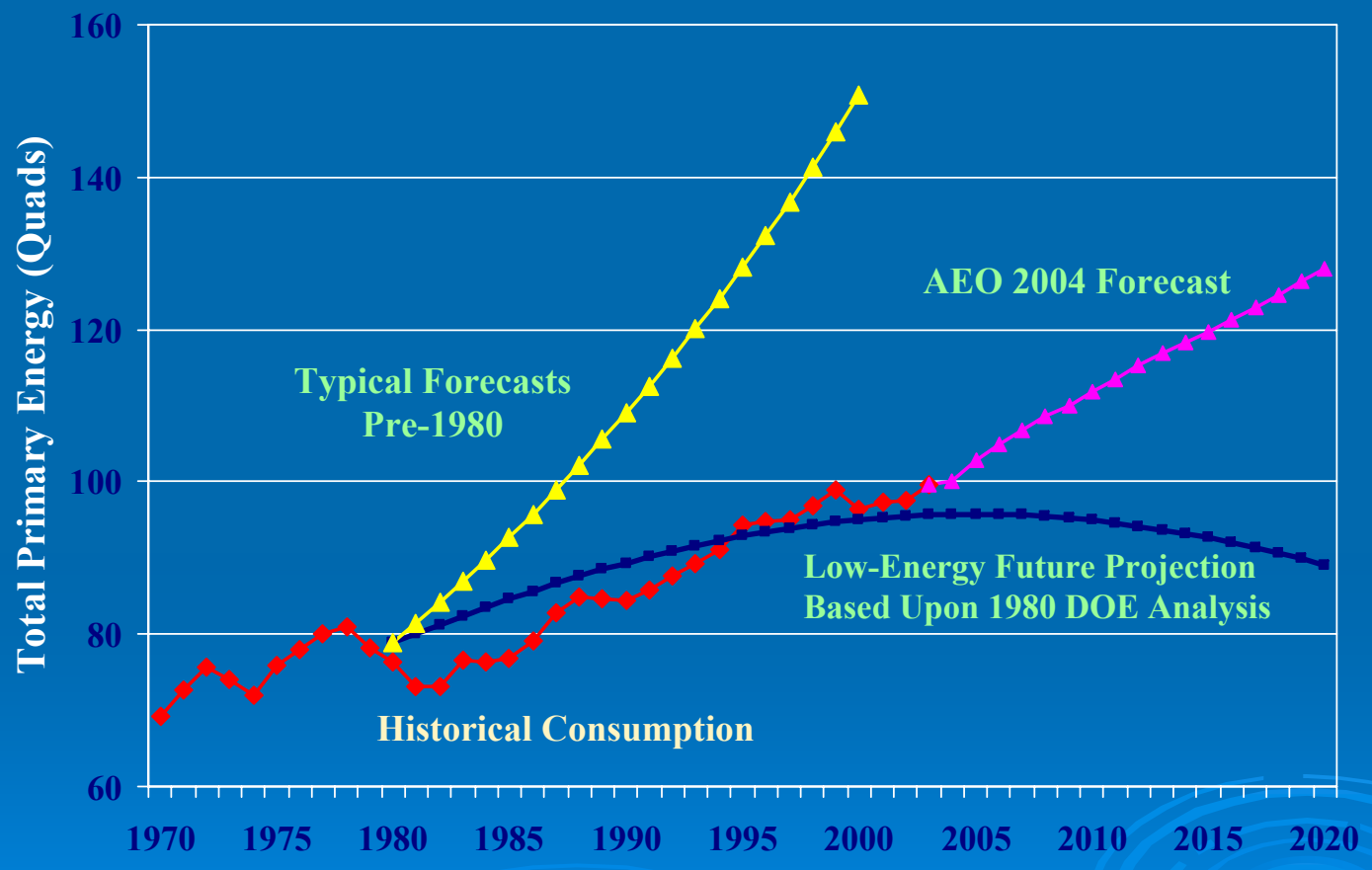
Comparison of U.S. Energy Projections: A Difference in Technology Assumptions



Source: AEO 2004, EPA estimates 2004, and 1980 DOE Policy Analysis

Lessons Learned from Long Range U.S. Energy Price and Quantity Forecasts

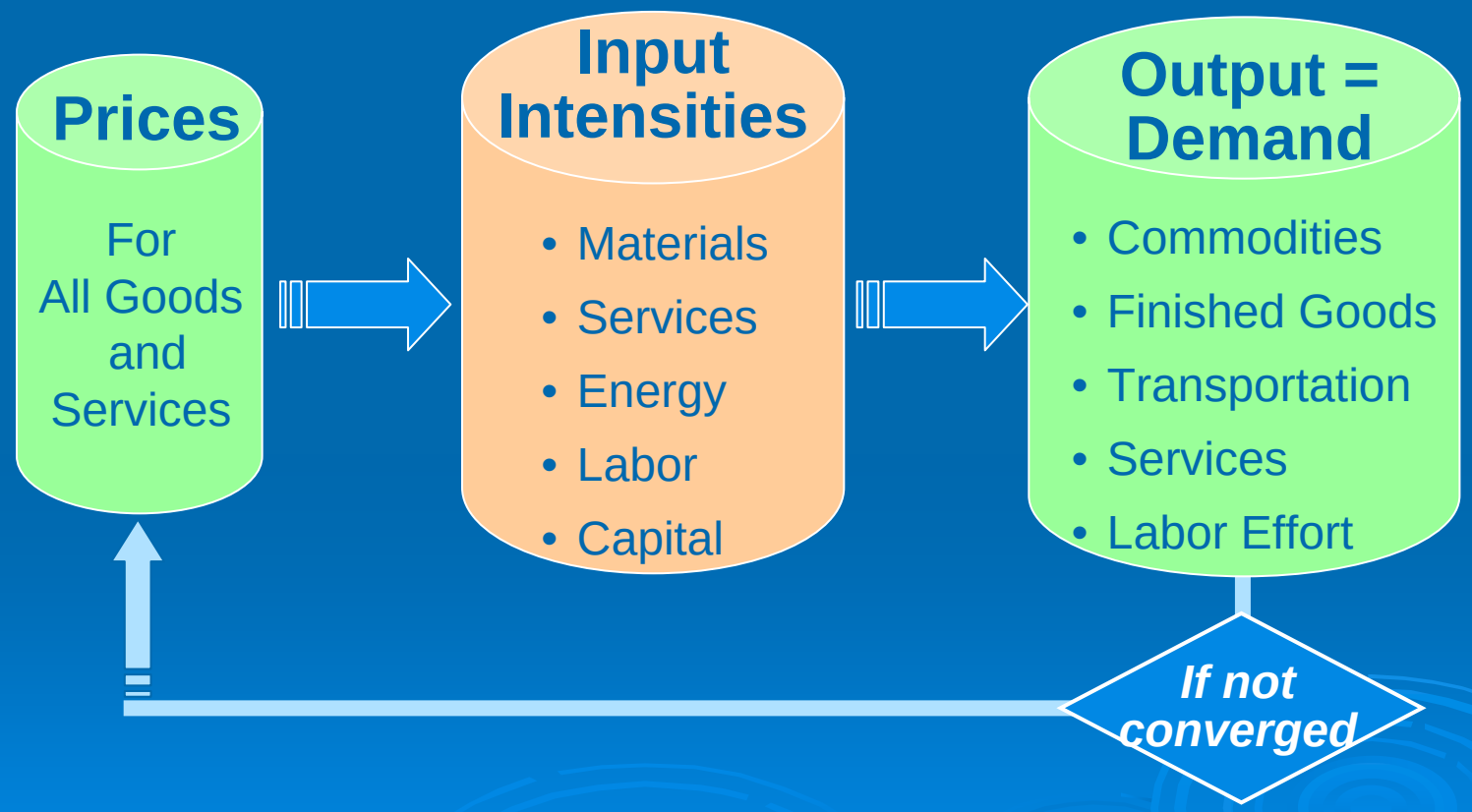
- Five U.S. energy forecasts conducted in early 1980s during the oil crisis show varying errors in projections, for year 2000:
  - Energy Demand: -5.2% (Median error)
  - U.S. Gross Domestic Product: -13.2% (Median error)
  - While the energy quantity estimates were roughly right, price forecasts were off significantly:
    - Industrial electricity prices: +125% (Median error)
    - World oil prices: +197%
    - Natural gas prices: +324%
- The economy has more-or-less met the demand projections with much weaker price signals than were anticipated.
- Suggesting we tend to underestimate the potential of technological changes and efficiency improvements in reducing energy, as well as the impact of regulatory and social policies (e.g., codes and standards, voluntary programs)

***Source: Alan H. Sanstad, et al, "Back To The Future: Long-Range U. S. Energy Price And Quantity Projections In Retrospect," LBNL, April 2004 (in revision).**

AMIGA Modeling System

- AMIGA is a comprehensive CGE modeling system that integrates the energy markets, technologies, and policies:
  - Examines the impact of changes in more than 200 individual sectors (in terms of both dollar measures and physical units).
  - Integrates a detailed energy market specification within a structural economic model.
  - Calculates both prices and macroeconomic variables such as consumption, investment, government spending, employment, and GDP.
  - Provides equilibrium paths from the present through the year 2050, with the capability of extending the time horizon out to 2100.

AMIGA Calculated Both Prices and Intermediate Demand Quantities



Computable – Modular Structure

- Vehicle Stock and Transportation
- Electricity Supply Capacity and Generation
- Process Transformations
- Product Manufacturing Activities
- Service Sectors and Government
- Industrial Capital Stock
- Buildings Capital Stock
- Non-carbon Greenhouse Gases
- Household Consumption
- Natural Gas Supply
- World Oil Pricing

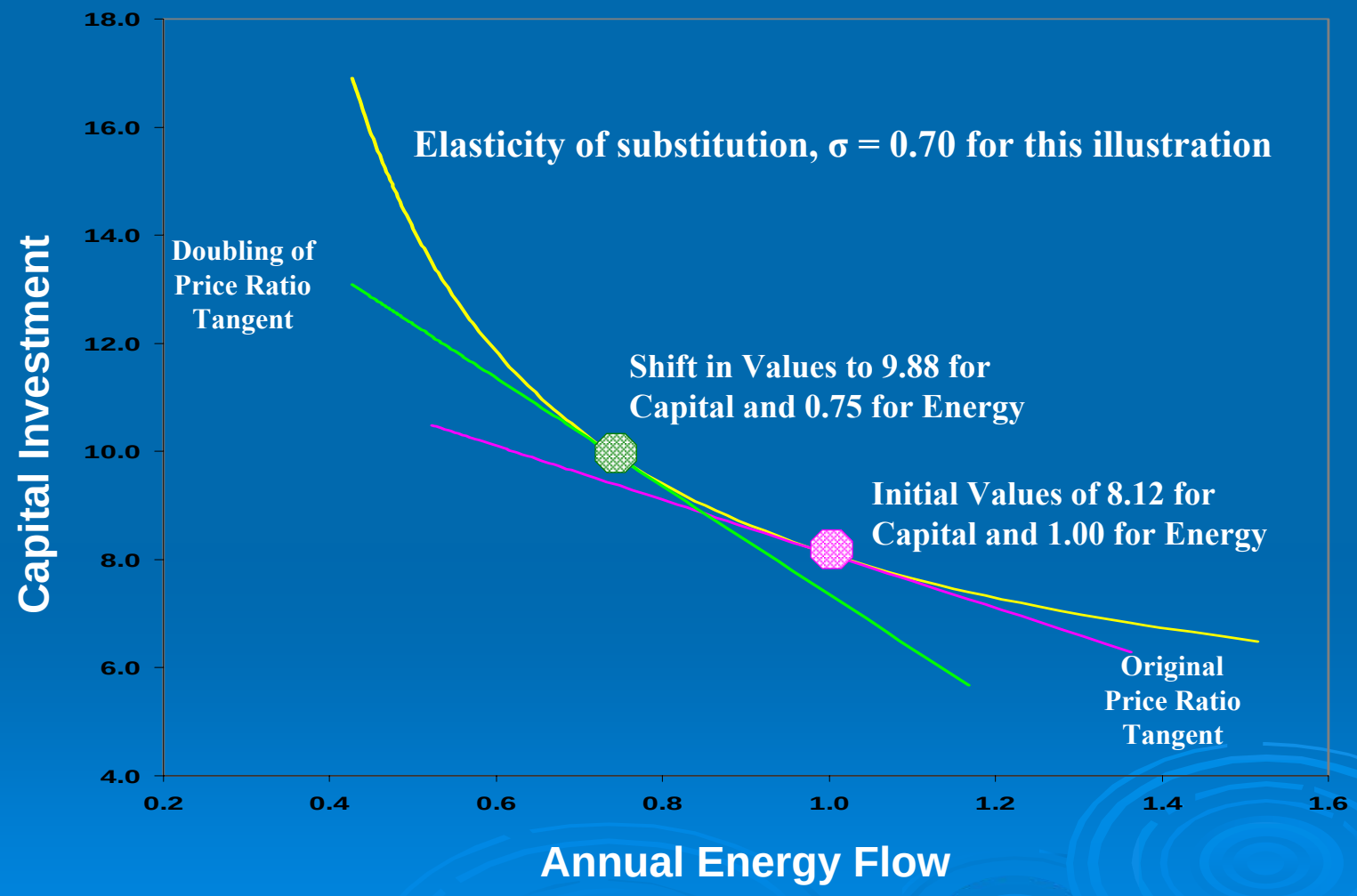
AMIGA Modeling System, Version 4.0

- Version 1.0 was a strictly energy-economic framework developed for DOE/EERE Office of Transportation Technologies (OTT) with a 2020 time horizon and used for preparing the OTT R&D Report to Congress.
- Version 2.0 included carbon emissions and tracked the NEMS Annual Energy Outlook and was used for Clean Energy Future (CEF) analysis.
- Version 3.0 incorporated the Argonne Unit Planning and Compliance model and SO_2, NO_x, and Hg emissions and trading and was used for the Jeffords-Lieberman analysis and EMF-19 scenarios.
- Version 3.1 increased representation of the transportation sector with a 2050 time horizon and was used for Pew Climate Center, Keystone scenario analysis, and EPA-Argonne Energy Future Scenarios.
- Version 4.0 adds the other (Non-CO2) greenhouse gases and a total of 15 regions of the world with a time horizon out to 2100.

Technology Representation in AMIGA

- New demand and capital stock replacement drive new industrial equipment sales;
  - Opportunities for efficiency improvements
- Energy-related services can be provided with alternative ratios of capital, labor, and energy
- Inelastic short-run energy demand responses provide opportunities for retrofits and operational improvements
- These efficiency opportunities are represented by the isoquants derived from a production function (i.e., production of energy-related services).

Energy Services Isoquant Showing Relationship Btw Capital, Energy, Price Ratio



Changes in Capital and Energy as a Result of Doubling the Energy Price Ratio

- Under the assumption that
  - energy prices increase by 50%
  - while hurdle rates decrease from 20% to 15%
- the price ratio will double
  - from 1.00 / 0.200 which equals 5.0
  - to 1.50 / 0.15 which equals 10.0
- In this case
  - Capital investment will increase from 8.12 to 9.88 (22%)
  - Annual energy flow will decrease from 1.00 to 0.75 (-25%)
- Project payback will be
  - (9.88 - 8.12) / 0.25 = 7.04 years under the old energy prices
  - (9.88 - 8.12) / (0.25 * 1.50) = 4.69 years with the new energy prices

The Model Also Adds Capacity for Energy End-Use Technologies

- End-use technologies based on
  - Engineering cost-of-energy estimates,
  - Supply function analysis, and
  - Consumer preferences based on a distribution of hurdle rates unique to end-use sector, energy service, and fuel type.
- Including
  - Light and heavy duty vehicles for both passenger and freight services,
  - Industrial processes, and
  - Building technologies.

Representing Technology Change: Isoquants

Data on Residential Refrigerators from the NEMS model for Year 2020

- Average Electricity Use = 519 kWh at a cost of $424
- Refrigerator 1 = 478 kWh at a cost of $600
- Refrigerator 2 = 460 kWh at a cost of $650
- Refrigerator 1 = 400 kWh at a cost of $950

With an Implied Elasticity of ~0.95

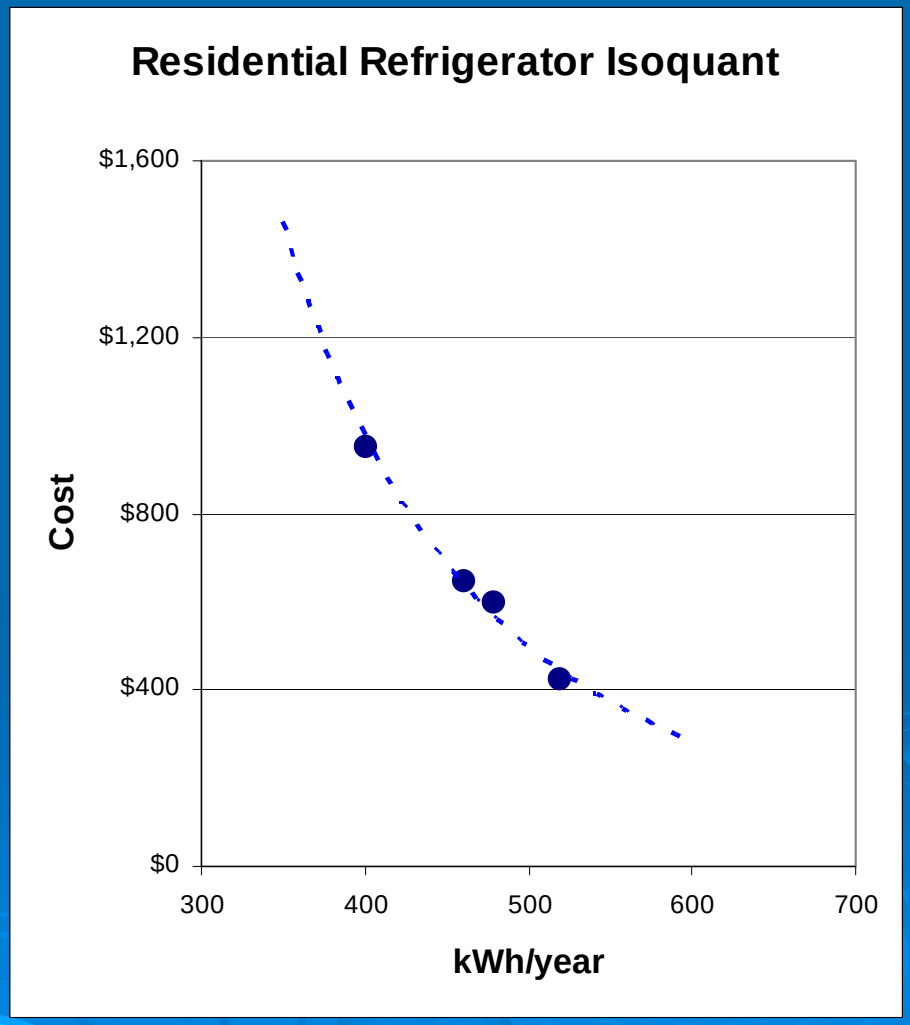


Illustration: Capital, Energy Use and Service Provision of Building Technology

$$Serv_{s,d,y} = \Sigma_j\{0.5 * as_{j,d,y} * Q_{j,d,y} + \Sigma surv_{j,y-\tau} * use_{j,y-\tau} * as_{j,d,\tau} * Q_{j,d,\tau}\}$$

$$Energy_{e,s,y} = \Sigma_j \Sigma_d\{0.5 * en_{j,d,y} * Q_{j,d,y} + \Sigma surv_{j,y-\tau} * use_{j,y-\tau} * en_{j,d,\tau} * Q_{j,d,\tau}\}$$

$$Invest_{s,y} = \Sigma_j \Sigma_d\{invt_{j,d,y} * Q_{j,d,y}\}$$

j, index over the set of capital stocks represented for the buildings sector

s, index over the end-use services represented (e.g., building shell, heating, cooling, ventilation, lighting)

There are multiple equipment options, *j*, available to supply each service, *s*

y, denotes current year

t, denotes previous vintages

d, denotes the decision-maker that chooses factor-intensities

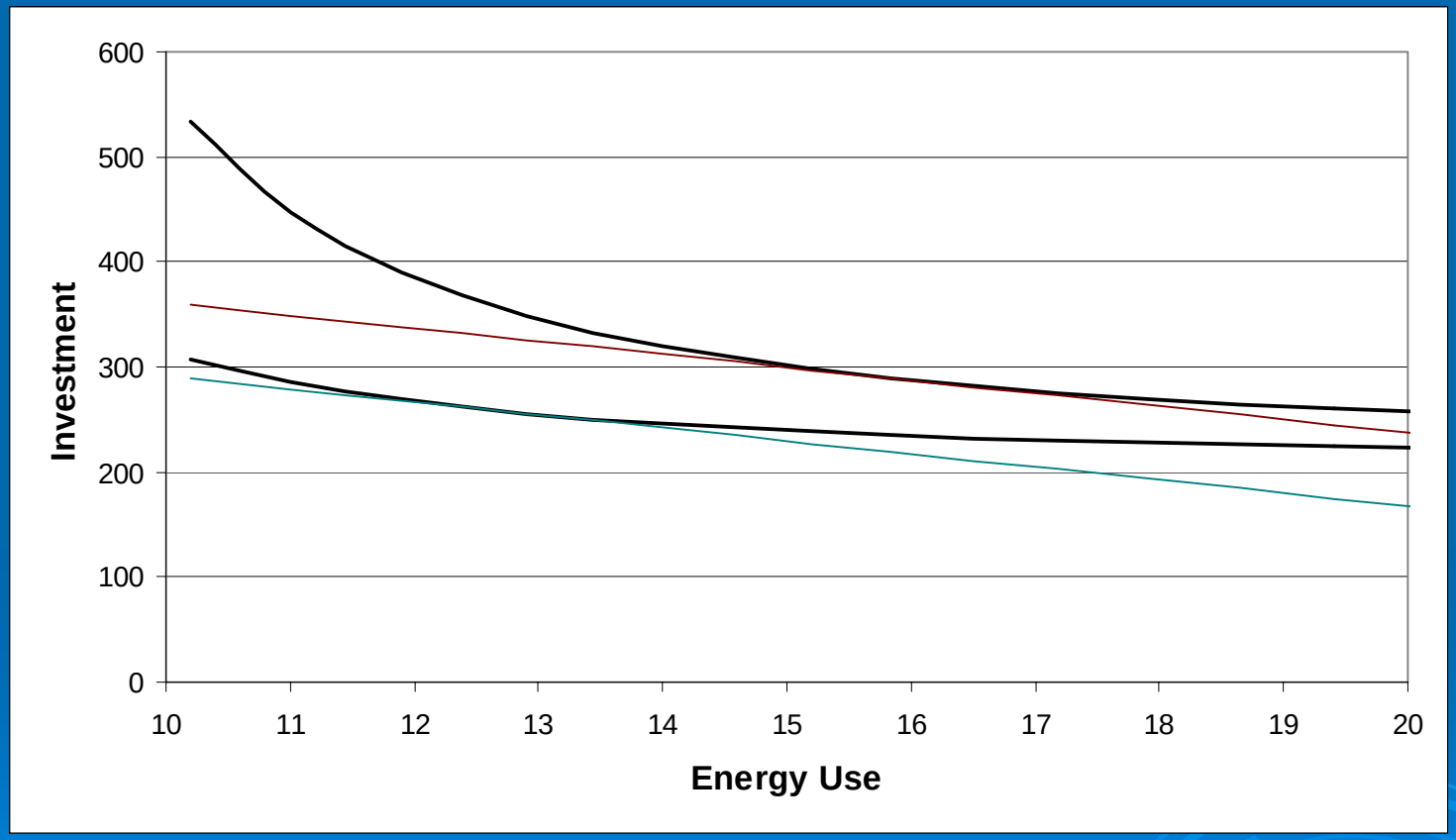
$Q_{j,d,y}$ denotes quantity of additions selected by *d* in year *y*

Let the intensities for service output, energy use of type *e* , and investment be denoted by $as_{j,d,y}$, $en_{j,d,y}$ and $invt_{j,d,y}$, respectively

The use fraction of equipment *j*, $use_{j,y-t}$, may deteriorate with age

The survival probability is also a function of age, $surv_{j,y-t}$

Shift in Isoquants Represents Technology Change



- The downward shift of isoquant indicates a given service output can be produced with less input of energy and capital

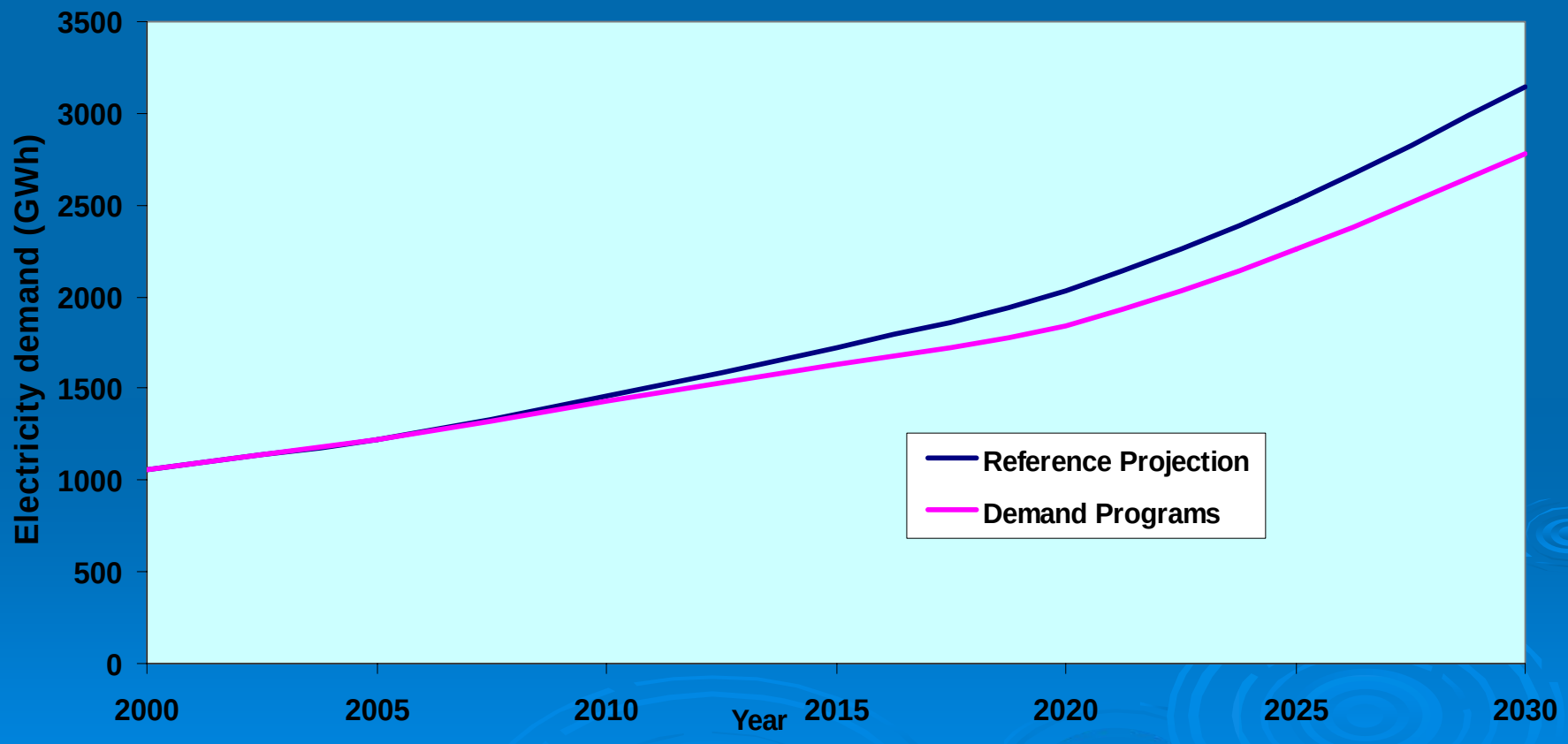
AMIGA China Module

- China is one of the countries treated in the AMIGA modeling system.
- Various benchmark economy data are derived from the Purdue University GTAP database (Global trade Analysis Project).
  - Final demand vector for goods and services
  - Inter-industry coefficients
  - Sector electricity and fuel intensities
- China is assumed to continue its rapid growth and modernization, but at somewhat lower rates than recently experienced.
- The energy intensity of providing energy-related services improves over time.
- Capital investment and stock vintaging for both end-use demand and energy supply technologies
- Relative capital equipment and operating cost data are derived from the EIA SAGE Model database

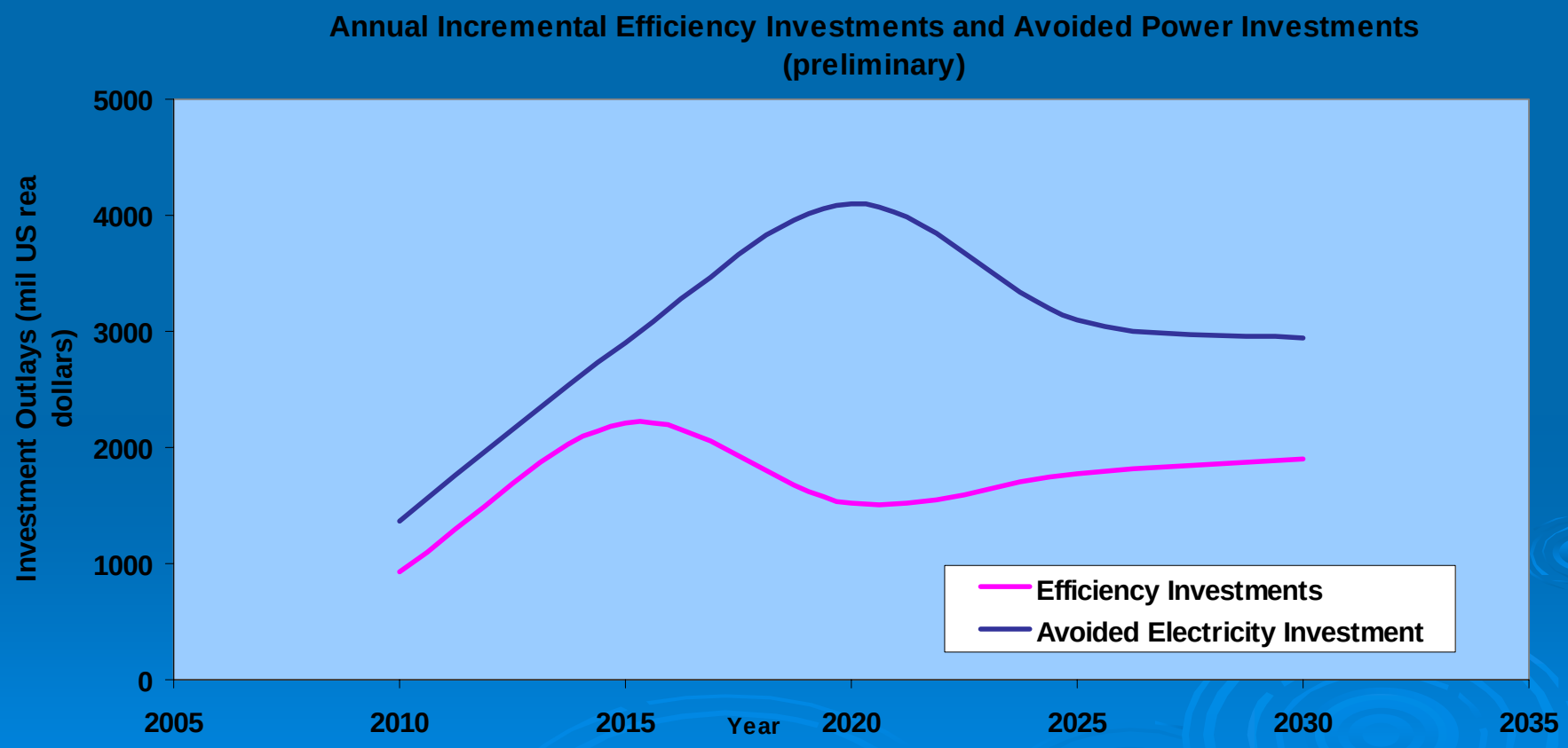
Energy Efficiency Scenario

- Employs a set of non-price policies:
  - Appliance and other equipment standards
  - Voluntary agreements with product manufactures, using USA Energy Star as an example
  - Building shell standards and lighting guidelines
  - Voluntary industry efficiency targets (CHP was not include in this analysis.)
- The incremental capital cost vs energy consumption savings tradeoff curves (i.e., isoquants for the production of energy-related services) are developed from technology characterizations.
- The reference electricity projection for China shows a 3.8% annual average growth in electricity demand from 2005 to 2030.
- Under the demand programs scenario, electricity demand is reduced by 12% in the year 2030 at about 2/3 cost of electricity generation.

Electricity Demand in China Can Reduce by 12% in 2030 with Moderate EE Policy



Investments in Energy Efficiency Yield Positive Economic Feedback



Saving Real Resources Through Energy Efficiency Policy

- Energy efficient investments save real resources in the economy; Resources can be channeled into other uses, raising the potential output of the economy.
- The figure shows greater savings in avoided power plant construction, relative to the incremental investment in electricity demand programs.
- About 60 GW of new generating capacity could be avoided by the year 2030. Assuming average efficiency of 42% (with average CO2 rate of 1000 lbs/MWh), roughly 100 million tonnes of CO2 are reduced in 2030.
- In addition to net savings of investment outlays, other costs are avoided through energy efficiency:
  - Coal, nuclear and other power plant fuel costs
  - Power plant operations and maintenance costs
  - Emissions of local air pollutants

Keeping Co-Benefits in the Picture

- Increased energy security
- Lower world oil prices, benefiting most countries
- Reduced criteria and toxic air pollutant emissions
- Reduced energy expenditures
- Increased disposable income by households
- Increased productivity associated with many energy efficiency technologies
- R&D and technology advances

However, technology alone will not solve climate change problem

- Prices are not the only determinant of energy-intensity ratios; market, institutional, social and cultural barriers all play important roles
- Non-technological options, behavioral or social changes could yield much more efficient energy savings, intensity improvements
- For example, transportation sector measures such as:
  - Vehicle mileage travel (VMT) reductions from better urban planning
  - Land use changes
  - Mitigation measures of urban sprawl
  - Public transportation

  All induce real, effective energy savings and GHG emissions reductions, while yielding multiple social benefits

Conclusions

- China has already undergone significant technology changes and energy efficiency improvements over the last 20 years
- The Government has set aggressive goals for energy savings for the next few decades
- China can achieve the energy efficiency improvements through:
  - Appliance efficiency standards
  - Advanced building technologies
  - Voluntary programs (e.g., Energy Stars, voluntary agreements)
- These technology policy measures will not only reduce GHG emissions, but also provide positive feedback in the economy as well as multiple social benefits

Next Steps

- Finish detailed mapping of end-use energy technology representation into AMIGA
  - Commercial, residential, industrial, and transportation sectors
- Complete multi-gas emissions scenarios for current EMF-21 exercise and report
- Continue support for the IEA's World Energy Outlook 2004 with estimates of energy efficiency investments
- Verify assumptions used in AMIGA China module and other regions in the world
- Collaborate with Chinese colleagues on appropriate technology costs and scenario analysis
- Explore the mapping of productivity impacts from efficiency investments

Nature of Economies:

"Working along with natural principles of development, expansion, sustainability, and correction, people can create economies that are more reliably prosperous…and that are also more harmonious with the rest of nature."

- Jane Jacobs