PANDA Modeling of China's Sustainability Issues

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1. Introduction

These notes introduce a new research tool that has been built study of China's long term sustainable development with detailed empirical assessment of linkages between economic structure, energy use patterns, and emissions of greenhouse gases and other pollutants. The Pollution and National Development Assessment (PANDA) model of the Chinese economy begins from a standard, state-of-the-art single country dynamic CGE model. The PANDA model for this is fully documented elsewhere (Roland-Holst: 2005) and here we only summarize the core model and discuss how it has been extended to address energy, resource, and sustainability issues. PANDA is designed for implementation at the national level, but has also been applied to individual Chinese provinces.

2. Core Model Overview

PANDA is in reality a constellation of research tools designed to elucidate economy-environment linkages in China. The schematics in Figures 2.1 and 2.2 describe the four generic components of the modeling facility and their interactions. This section provides a brief summary of the formal structure of the PANDA model. For the purposes of this research, we refer to a new 2004 China Social Accounting Matrix (SAM), that is currently under development in collaboration with the National Bureau of Statistics. The proposed SAM includes 50 sectors and PANDA will operate with this as the baseline level of aggregation.

2.1. Structure of the CGE Model

Technically, a CGE model is a system of simultaneous equations that simulate price-directed interactions between firms and households in commodity and factor markets. The role of government, capital markets, and other trading partners are also specified, with varying degrees of detail and passivity, to close the model and account for economywide resource allocation, production, and income determination.

The role of markets is to mediate exchange, usually with a flexible system of prices, the most important endogenous variables in a typical CGE model. As in a real market economy, commodity and factor price changes induce changes in the level and composition of supply and demand, production and income, and the remaining endogenous variables in the system. In CGE models, an equation system is solved for prices that correspond to equilibrium in markets and satisfy the accounting identities governing economic behavior. If such a system is precisely specified, equilibrium always exists and such a consistent model can be calibrated to a base period data set. The resulting calibrated general equilibrium model is then used to simulate the economywide (and regional) effects of alternative policies or external events.

The distinguishing feature of a general equilibrium model, applied or theoretical, is its closed-form specification of all activities in the economic system under study. This can be contrasted with more traditional partial equilibrium analysis, where linkages to other domestic markets and agents are deliberately excluded from consideration. A large and growing body of evidence suggests that indirect effects (e.g., upstream and downstream production linkages) arising from policy changes are not only substantial, but may in some cases even outweigh direct effects. Only a model that consistently specifies economywide interactions can fully assess the implications of economic policies or business strategies. In a multi-country model like the one used in this study, indirect effects include the trade linkages between countries and regions which themselves can have policy implications.

The model we use for this work has been constructed according to generally accepted specification standards, implemented in the GAMS programming language, and calibrated to the new China SAM being estimated for the year 2004.[1] The result is a single economy model calibrated over the fifteen-year time path from 2005 to 2030. Using the very detailed accounts of the China SAM, we include the following in the present model:

[1] See e.g. Meeraus et al (1992) for GAMS or consult www.gams.com.

Figure 2.1: Component Structure of the PANDA Modeling Facility

Development of the China modeling capacity is proceeding in four distinct component areas.

1. Core CGE model
2. Emissions module
3. Energy supply and demand analysis, including electricity
4. Modeling of resource use, including water and land

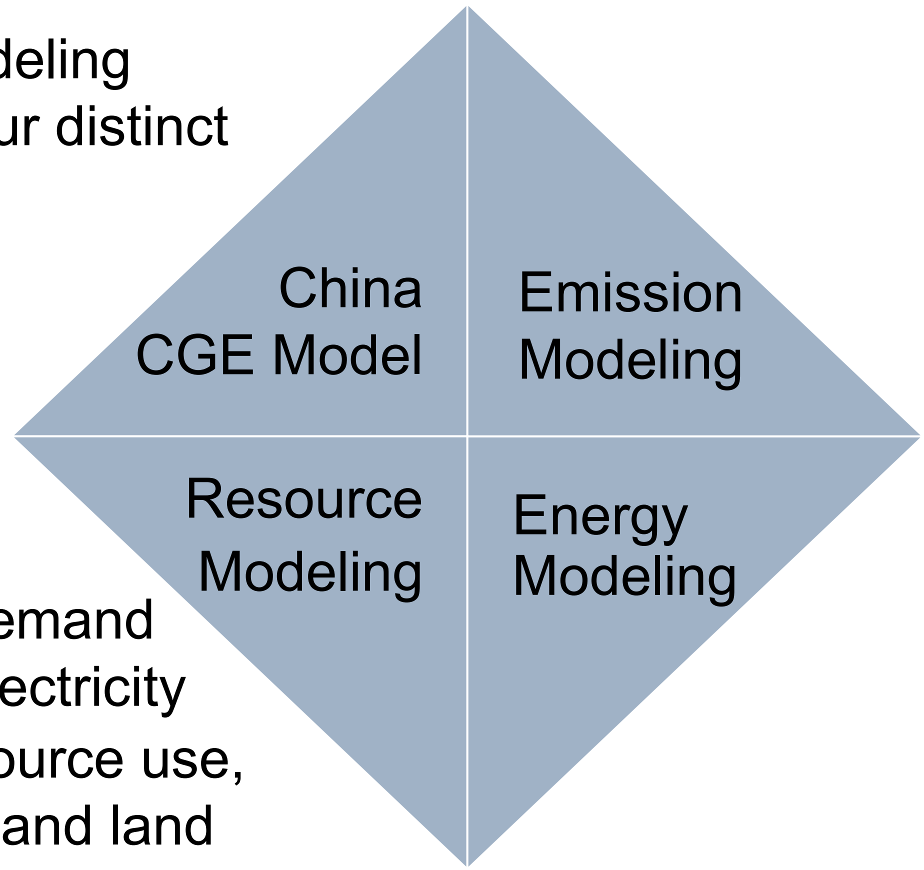
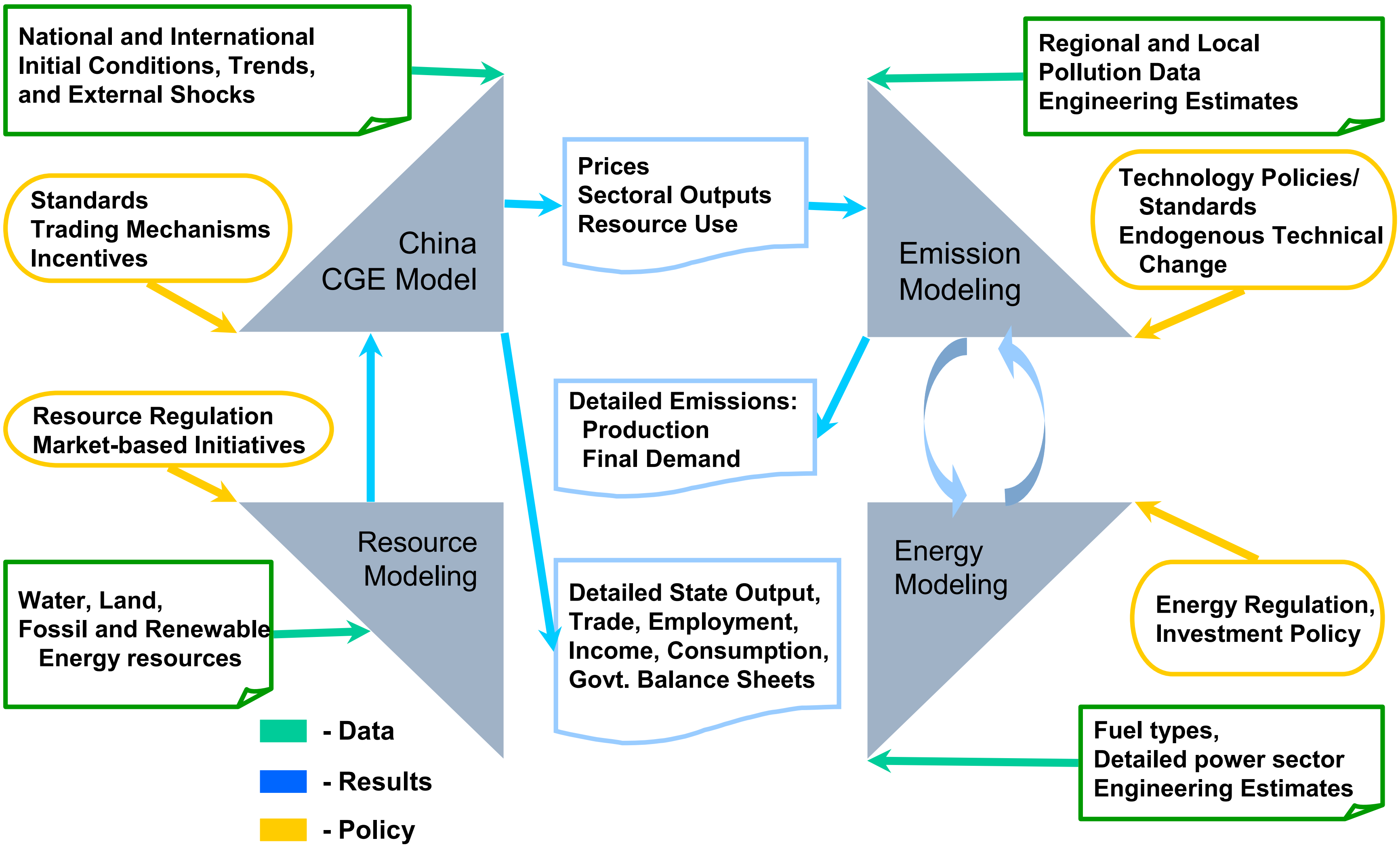


Figure 2.2: Schematic Linkage between Model Components



2.1.1. *Production*

All sectors are assumed to operate under constant returns to scale and cost optimization. Production technology is modeled by a nesting of constant-elasticity-of-substitution (CES) functions.

In each period, the supply of primary factors — capital, land, and labor — is usually predetermined. The model includes adjustment rigidities. An important feature is the distinction between old and new capital goods. In addition, capital is assumed to be partially mobile, reflecting differences in the marketability of capital goods across sectors.

Once the optimal combination of inputs is determined, sectoral output prices are calculated assuming competitive supply (zero-profit) conditions in all markets.

2.1.2. *Consumption and Closure Rule*

All income generated by economic activity is assumed to be distributed to consumers. Each representative consumer allocates optimally his/her disposable income among the different commodities and saving. The consumption/saving decision is completely static: saving is treated as a "good" and its amount is determined simultaneously with the demand for the other commodities, the price of saving being set arbitrarily equal to the average price of consumer goods.

The government collects income taxes, indirect taxes on intermediate inputs, outputs and consumer expenditures. The default closure of the model assumes that the government deficit/saving is exogenously specified. The indirect tax schedule will shift to accommodate any changes in the balance between government revenues and government expenditures.

The current account surplus (deficit) is fixed in nominal terms. The counterpart of this imbalance is a net outflow (inflow) of capital, which is subtracted (added to) the domestic flow of saving. In each period, the model equates gross investment to net saving (equal to the sum of saving by households, the net budget position of the government and foreign capital inflows). This particular closure rule implies that investment is driven by saving.

2.1.3. Trade

Goods are assumed to be differentiated by region of origin. In other words, goods classified in the same sector are different according to whether they are produced domestically or imported. This assumption is frequently known as the *Armington* assumption. The degree of substitutability, as well as the import penetration shares are allowed to vary across commodities. The model assumes a single Armington agent. This strong assumption implies that the propensity to import and the degree of substitutability between domestic and imported goods is uniform across economic agents. This assumption reduces tremendously the dimensionality of the model. In many cases this assumption is imposed by the data. A symmetric assumption is made on the export side where domestic producers are assumed to differentiate the domestic market and the export market. This is modeled using a *Constant-Elasticity-of-Transformation* (CET) function.

2.1.4. Dynamic Features and Calibration

The current version of the model has a simple recursive dynamic structure as agents are assumed to be myopic and to base their decisions on static expectations about prices and quantities. Dynamics in the model originate in three sources: i) accumulation of productive capital and labor growth; ii) shifts in production technology; and iii) the putty/semi-putty specification of technology.

2.1.5. Capital accumulation

In the aggregate, the basic capital accumulation function equates the current capital stock to the depreciated stock inherited from the previous period plus gross investment. However, at the sectoral level, the specific accumulation functions may differ because the demand for (old and new) capital can be less than the depreciated stock of old capital. In this case, the sector contracts over time by releasing old capital goods. Consequently, in each period, the new capital vintage available to expanding industries is equal to the sum of disinvested capital in contracting industries plus total saving generated by the economy, consistent with the closure rule of the model.

2.1.6. The putty/semi-putty specification

The substitution possibilities among production factors are assumed to be higher with the new than the old capital vintages — technology has a putty/semi-putty specification. Hence, when a shock to relative prices occurs (e.g. the imposition of an emissions fee), the demands for production factors adjust gradually to the long-run optimum because the substitution effects are delayed over time. The adjustment path depends on the values of the short-run elasticities of substitution and the replacement rate of capital. As the latter determines the pace at which new vintages are installed, the larger is the volume of new investment, the greater the possibility to achieve the long-run total amount of substitution among production factors.

2.1.7. Dynamic calibration

The model is calibrated on exogenous growth rates of population, labor force, and GDP. In the so-called Baseline scenario, the dynamics are calibrated in each region by imposing the assumption of a balanced growth path. This implies that the ratio between labor and capital (in efficiency units) is held constant over time. When alternative scenarios around the baseline are simulated, the technical efficiency parameter is held constant, and the growth of capital is endogenously determined by the saving/investment relation.

3. Emissions

3.1. Overview

Pollution modeling in a CGE framework has a long and diverse history. Apart from small, one-off studies, however, the main standard setters were the OECD's GREEN model, MIT's Global Model (based on Green), and a series of country studies done at the OECD Development Centre in the mid-1990's. All three of these had their origins with the same group of people, Dominique van der Mensbrugghe is the only person who has worked with all three, establishing GREEN with colleagues at OECD, transferring this capacity to the MIT researchers, and collaborating with David Roland-Holst and others on the country studies. In addition to this work, there have been a number of studies of carbon trading with single country models.

Since Dominque's departure from OECD, GREEN's development slowed substantially. In the meantime, the MIT group made substantial effort to extend their global approach and embed it in more scientific models of pollution and meteorology. In particular, the have devoted considerable resources to experimentation with technical parameters and specification choice in these models (Sokolov et al:2005).

3.2. PANDA's Current Specification of Emissions

The PANDA model builds on the OECD experience and incorporates more recent elements of the MIT approach that are appropriate to a single country approach. At the same time, PANDA extends the scope of emissions studies in two ways: more types of emissions are tracked and emissions in both production and consumption are modeled.

PANDA captures emissions from production activities in agriculture, industry, and services at the same level of detail as the SAM, as well as emissions arising from final demand and use of final goods (e.g. appliances and autos). This is done by calibrating emission functions to each of these activities that vary depending upon the emission intensity of the inputs used for the activity in question. Following standards set in this research literature (e.g., Jacoby et al: 2004) emissions in production are modeled as factors inputs. Emission levels have an underlying monotone relationship with production, but can be reduced by increasing use of other factors such as capital and labor. The latter can represent investments in lower intensity technologies, process cleaning activities, etc. An overall calibration procedure fits observed intensity levels to baseline activity and other factor/resource use levels.

The model has the capacity to track 13 categories of individual pollutants and consolidated emission indexes, each of which is listed in Table 2.1 below. Our focus in the current study is the emission of CO2 and other greenhouse gases, but the other effluents are of relevance to a variety of environmental policy issues. For more detail, please consult the full model documentation.

Table 3.1: Emission Categories

Air Pollutants		
1.	Suspended particulates	PART
2.	Sulfur dioxide (SO_2)	SO_2
3.	Nitrogen dioxide (NO_2)	NO_2
4.	Volatile organic compounds	VOC
5.	Carbon monoxide (CO)	CO
6.	Toxic air index	TOXAIR
7.	Biological air index	BIOAIR
Water Pollutants		
8.	Biochemical oxygen demand	BOD
9.	Total suspended solids	TSS
10.	Toxic water index	TOXWAT
11.	Biological water index	BIOWAT
Land Pollutants		
12.	Toxic land index	TOXSOL
13.	Biological land index	BIOSOL

As the name of the model implies, PANDA was first designed to simulate economy-environment linkages, with special reference to greenhouse gases (GHGs). To this end, the model can be calibrated to, and will simulate changes in, criteria pollutants from each sector and household group as a result of direct input use and energy consumption. For non-CO_2 GHG's like methane, HFCs, etc., CO_2-equivalent emissions are imputed using estimates of Global Warming Potential (GWP). About a dozen pollutants can be tracked (see the table above), in the aggregate and for every sector and household.

3.3. Data Requirements

Emissions data are increasingly available in China, but their detail, timeliness, and accuracy vary widely. To fully calibrate PANDA requires annual emissions information for every sector and household/commodity combination, and this information is not yet incorporated into the model. In collaboration with Chinese agencies with line responsibility for these policies and data associated with them, I believe we could assemble a consistent economywide emissions database relatively quickly. This data would be of independent interest to a wide policy and research audience.

At the present time, PANDA is calibrated with a combination of direct Chinese estimation and values imputed from authoritative international sources. These data are quite serviceable for general scenario analysis, but it would be desirable to update some information with more direct estimates.

4. Energy

4.1. Overview

Rapid growth and modernization in China make energy an extremely important strategic sector. Because of energy's linkage to growth, trade, and rising living standards, it is essential for policy makers to have visibility about evolving patterns of energy supply and demand. Moreover, energy's environment linkages have far reaching implications that need deeper understanding and forward-looking policy initiative.

Over the last decade, China has gone from being a small net exporter of energy fuels to the world's second largest importer. At the same time, China's long term transition to a post-industrial economy will inexorably increase the importance of residential electricity and transport demand. The latter are the primary drivers of energy demand and greenhouse gas emissions in most OECD countries.

From a sustainability perspective, China's policy makers need to consider more than just supply and demand balances. Carbon fuels are a major source of CO2 emissions (over 90% for many countries) and in China's case they are also an important traded commodity. PANDA disaggregates several fuel types (coal, gasoline, LNG, diesel, and others) and tracks their use by sector and household. In addition to this, we have disaggregated an important energy sector, electricity, to unprecedented detail for CGE work. Generally, we are trying to decompose technology-fuel pairs across this sector to evaluate the two primary determinants of energy sustainability: technological change and fuel substitution. We believe it is extremely important to be able to track detailed patterns of emergent supply and demand in this sector. Industry gets a lot of attention now, but over the long term, electricity and transportation services will be the most important sources of Chinese GHGs.

Over the next 15 years, China's energy concerns will be dominated by the need to sustain 6 to 10 percent annual demand growth, while raising standards for human and ecological health. To reconcile and achieve these objectives will require deeper understanding of the complex linkages between economic activity, energy resources, and the environment. Empirical GE models like PANDA can elucidate energy-economy-environment interactions and inform more economically and socially effective polices.

Because of its fundamental economic importance, rapid expansion, and slow capital turnover, the power sector will be a salient component of China's medium-term growth experience. Even conservative growth estimates imply that, over the next fifteen years, China must add generation that exceeds Europe's entire installed capacity (850-900GW against 780GW for the 2004 EU). Changes in electricity prices have pervasive upstream (e.g., primary energy prices) and downstream (industry structure, consumption patterns, etc.) linkage effects, and technology choice ultimately determines patterns of resource use. In terms of technology adoption, fuel sources, and emission characteristics, investment decisions made now in China's electricity sector will have economic and environmental implications lasting 30 to 50 years.

While macroeconomic trends can influence the electricity sector through overall growth and investment patterns, equally important are feedbacks from electricity policies to the rest of the economy. The sector is a highly regulated one and, and polices toward prices, investment, and technology can exert complex influences on the rest of the economy. Furthermore, energy and electricity markets in China exhibit significant segmentation. Although many of the country's regional electricity grids have limited interconnection, China has not established a grid at the national level and is unlikely to have one serving up to half of GDP over the period under consideration. For the medium term, electricity sector markets will remain region specific, and policies need to take account of underlying heterogeneity in resource availability and service requirements.

Within regional electricity grids, three interrelated areas have not received adequate empirical attention: energy efficiency, environmental policy, and energy markets. Each of these is well suited to policy simulation modeling.

Energy Efficiency • Comparing the costs and dynamic benefits from demand-side improvements in energy efficiency ***Environmental Policy*** • Measuring the economy-wide costs and potential emissions reductions of regulatory approaches to greenhouse gas mitigation. ***Energy Markets*** • Measuring the effects of institutional changes on electricity and fuel prices, as well as the economy-wide effects of changing prices along the electricity supply chain.

Energy Efficiency

Background. As part of the 11th Five-Year Plan, the State Council established an objective of reducing energy intensity by 20 percent by 2010. As a significant proportion of China's final energy consumption, electricity end-use is an obvious candidate for efficiency improvements.

Opportunity. While loose efficiency targets have been outlined for specific industries, a more thorough analysis of the costs and economy-wide gains from energy efficiency programs, particularly at a provincial level, has yet to be undertaken.

Approach. Measuring the costs and gains from efficiency is well suited to general equilibrium analysis because of its complex linkage and feedback effects. Producers pass along costs and savings to consumers, whose reduced or increased consumption levels slow or spur demand for other goods and services, with corresponding reductions or increases in production and energy use. Provincial-level and regional CGE models offer a powerful tool for analyzing the effects of different levels of investment in energy efficiency.

Environmental Policy

Background. As the human health and productivity costs of air pollution become more apparent in China, controlling emissions from power plants has become a higher priority. The scale of new generation capacity, as well as very high levels of reliance on coal-fired generation in some regions, poses important challenges to medium-term objectives for controlling emissions through pollution fees or feed-in tariffs.

Opportunity. Regional SO_2 and NO_x cap and trade schemes could play an important role in encouraging further emissions reductions and lowering compliance costs, but their economic viability remains largely unstudied.

Approach. By identifying dynamic cost thresholds, a general equilibrium approach to analyzing the economics of cap and trade schemes can offer essential insights about emissions trading. In particular, grid-level modeling can show how trading schemes might work across provinces with different resource endowments, achieving aggregate cost savings from trading. Simulation work is also an ideal context for experimentation with the complex incentive properties of cap and trade, including rights allocation, revenue recycling, banking, safety values, etc.

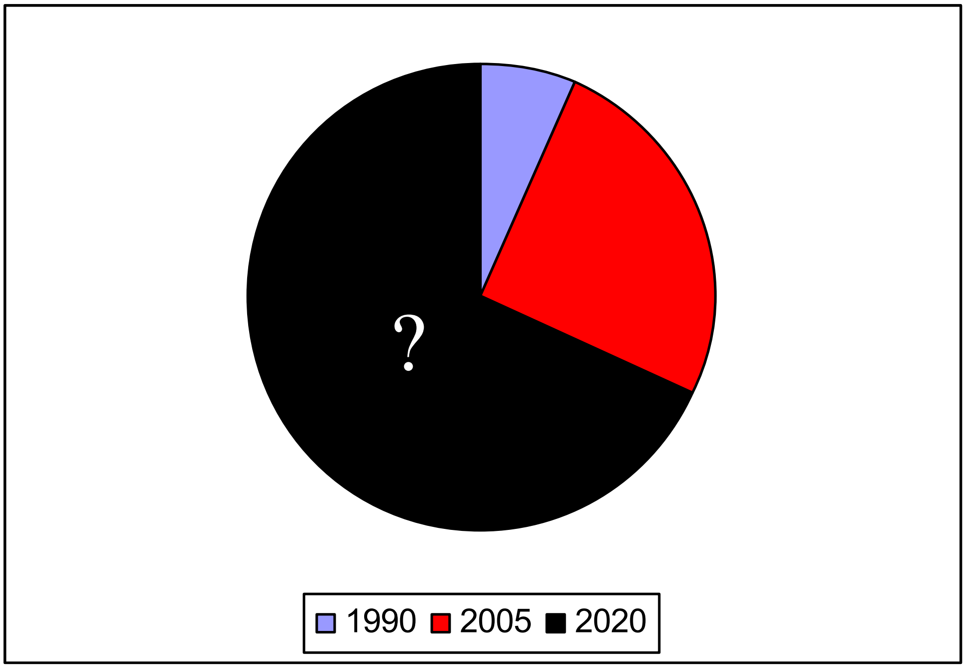
Energy Markets

Background. China's electricity sector began a process of deregulation in 2002 with the ultimate aim of creating a competitive electricity industry. Although electricity prices are still set by the NDRC, there is considerable interest within China in liberalizing electricity prices, including competitive bidding systems like those used in Europe and the U.S.

Opportunity. Despite their importance to overall sector development, as well as the interplay among efficiency, environmental policy, and electricity price regimes, there is still a lack of understanding of how institutional changes affecting electricity prices in China might be transmitted through regional grids, particularly those with high fossil fuel dependence.

Approach. General equilibrium modeling is ideally suited to tracing price interactions, and it can shed important light on the energy supply chain that links fuel prices, electricity prices, and government, business, and household income and expenditure. In both regulated and unregulated price regimes, regional CGE models can identify impacts of changes in efficiency and environmental policy on prices and economic structure at all levels.

Figure 1. China's Installed Generation Capacity, 1990, 2005, and estimated 2020



Sources: 1990 to 2004 installed capacity data are from www.eia.doe.gov; 2004 data are from China Electric Power Statistical Yearbook; 2005 data are from various online estimates.

China's installed capacity in 1990 was 138 GW; by 2005 it had reached 510 GW. The black area represents 870 GW, or annual demand growth of 8, 7, and 6 percent between 2005-2009, 2010-2014, and 2015-2020, respectively.

Assuming that around 70 percent of China's generation needs (609 GW) continue to be met through coal:[2]

- At current capital costs for coal-fired power plants (~4,000 yuan/kW), 609 GW translates to 2.4 trillion yuan in investment needs
- Annual coal consumption from new generating units would reach nearly 1.3 billion tons by 2020
- Assuming all new plants are equipped with 95 percent efficient FGD units, controlled SO_2 emissions from new generating units (~1.3 million tons) would be equivalent to one-third of uncontrolled 1990 SO_2 emissions from coal-fired power plants (~4 million tons) by 2020

[2] All calculations assume a capacity factor of 0.63, a coal heating value of 25.1 GJ/ton, a thermal efficiency of 0.38, a coal carbon content of 0.8, and complete combustion.

- At roughly 3.7 billion tons, CO_2 emissions from new generating units would be more than 1.5 times total U.S. 2004 emissions

4.2. PANDA's Current Specification

To model detailed patterns of energy use, PANDA distinguishes six fuel types (coal, natural gas, gasoline, diesel, petroleum, and other). Each of these is an independent factor of production in the energy bundle of the prototype CGE, and also represents a different commodity in final demand and trade. Thus there are independent price systems for all these fuel types, and their substitution possibilities depend on a combination of relative prices, tastes, and technology.

For the important electricity sector, PANDA follows standard CES/Leontief production technology, but disaggregates this sector in a special way to capture its detailed structure and essential heterogeneity. In particular, the national model specifies a total of six electricity sectors, representing the main producing entities in China. Each of these is then decomposed as a singe sector that aggregates up to a dozen individual production functions depending on different fuel-technology pairs used to produce electricity. Each pair is represented by an analogous CES function, but calibrated to different factor and input share parameters and technical parameters depending on the underlying generation technology. Using this approach, we strive to capture the diverse technology portfolio of each major generator, and thereby to more accurately simulate an adjustment process that must include both between firm and within firm technical change. This approach is more data intensive, but it yields essential information about adjustment patterns in response to changing resource availability, energy prices, and regulatory policies such as cap and trade, standards, etc. To better understand PANDA's approach to disaggregating the electricity sector, some institutional background can be helpful.

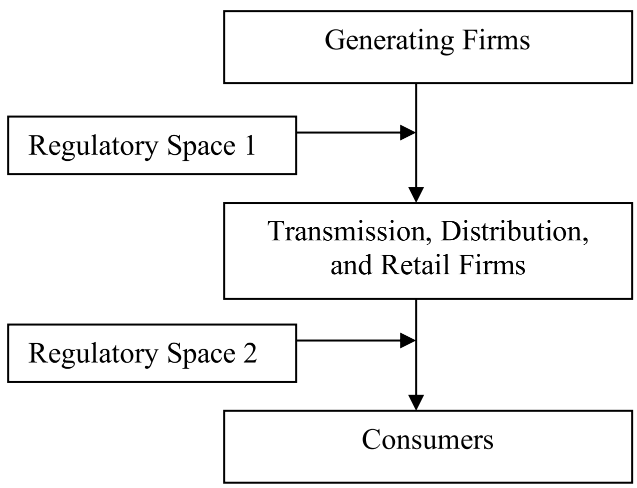
4.3. Institutional Framework

China's once vertically integrated electricity sector was "unbundled" into five generating companies and two grid companies in 2002. In 2004, the five generating companies controlled 35 percent of the China's total generating assets; the grid companies sold 97 percent of China's power.

Whereas reforms have led to a diversification of ownership and investment on the generating side, the transmission, distribution, and retail (TDR) side still operates under a utility model similar to that in OECD countries. Because of this, as the generation side becomes increasingly complex institutionally the TDR side will become more attractive as a regulatory locus.

Where regulation eventually accrues has important implications for measuring policy induced change in the power sector. Modeling of sector policies should follow regulatory trends; as the below figure suggests, this entails choosing between a generator-based or a transmission-distribution-retailer-based framework.

Figure 4.1: Space for Regulatory Intervention in the Power Sector



Regulatory Space 1. Industry behavior is primarily regulated through feed-in tariffs and direct demands on generating companies. For instance, efforts to control SO2 emissions from the electricity industry have largely focused on new source requirements or feed-in tariffs — the rates paid to generating companies for power. In the former case, beginning in 2004 the NDRC has required all new generation to install flue gas desulfurization (FGD) units. In the latter case, as part of a general tariff increase in June 2006 the NDRC included a .015 yuan/kWh increase for generating units that have installed FGD equipment.

Regulatory Space 2. Industry behavior is primarily regulated through procurement requirements on TDR firms. The state of California's Emissions Performance Standard, for instance, requires that power purchased and sold by the state's electricity retailers is as clean as a combined cycle gas turbine (CCGT). Although the TRD sectors have not typically been a focus of regulation in China, as the generating industry becomes increasingly diverse and complex, regulating TRD might become preferred to regulating generators.

In China, generation is responsible for approximately 70 percent of the retail cost of electricity, with transmission and distribution responsible for the remaining 30 percent. The 42-sector SAM aggregates the power sector into a single vertically integrated firm, and this 70-30 rule provides a means of disaggregation.

4.4. Fuel-Technology Framework

Data for China's power sector are typically classified by fuel source: thermal (huodian), hydro (shuidian), nuclear (hedian), and more recently wind (fengdian).

Thermal generation includes three primary fuel categories: coal, petroleum distillates (primarily fuel oil and diesel), and natural gas. Of these, coal comprises the vast majority — roughly 80 percent in 2004. With world oil prices on an upward trend, oil-based generators have struggled to maintain profitability and a significant number of non-petroleum industry power plants have converted their boilers to burn coal rather than oil products.

Coal-fired generation in China is entering into a era of technological change. Whereas small and medium-sized (< 50, 100, 200, 300 MW) conventional pulverized coal units once dominated the landscape, higher volatility in coal prices will likely mean that, over time, more efficient, larger units (300, 500, 600 MW) will increasingly displace less efficiency, smaller units. In the same vein, new, more efficient technologies, such as ultra supercritical and integrated gasification combined cycle (IGCC), will make rapid inroads into the sector. Either for larger (> 100 MW) existing or new plants, no other fuel-technology pairs can compete with coal on a levelized basis; coal's main competition is among coal-fired generating technologies rather than between coal and other fuels.

The use of natural gas in electricity generation has been limited by supply constraints and concerns over an over-reliance on imported LNG. Eased supply constraints from overland pipelines should alleviate some of these concerns, but natural gas capacity is only projected to reach 60 GW (of an added 400-700 GW) by 2020.

Expanded use of natural gas in the power sector will likely be driven by the twin factors of reliability and declining load factor rather than simple cost competitiveness. In the former case, increased value added in China's manufacturing sector will put pressure on grid companies to improve the reliability of supply. With shorter lead times and lower start up costs, on a per hour — rather than a levelized per kWh — basis, natural gas may be cost effective long before it is cost competitive with coal on a per kWh basis. Currently, natural gas is around 20-50 percent more expensive on a per kWh basis than coal.

Declining load factor (average load / peak load) will also drive greater use of natural gas in generating electricity. Electricity generating capacity is built to meet peak, rather than average, load. As time-sensitive (e.g., with air conditioners) residential consumption increases, China's load factor (currently around 0.8) will gradually decrease (California's load factor is around 0.5-0.6) and the amount of new generation running at low capacity factor will have to increase to meet the peak. With lower start up costs, natural gas "peakers" have typically played this role in OECD countries.

Hydro includes both large-scale hydro (e.g., the Three Gorges Dam) and small-scale hydro. The levelized costs of hydropower are likely less downwardly mobile than other generation sources. Nuclear and wind costs are roughly double the cost of coal-fired generation, but both are likely to decrease in cost as a greater share of components are manufactured domestically.

The 2002 SAM does not separate electricity and heat provision. Because of its lower costs and scale, heat can likely be subtracted out on an average percentage basis. Ideally, because of their interlinkages (i.e., through cogeneration) electricity and heat should be modeled together. One reason that small coal-fired power plants continue to be economically viable in China is because they cogenerate electricity and heat.

However, the economics of the electricity-heat interaction are still opaque and data may not be sufficient to support modeling efforts.

4.5. Data Requirements

To effectively calibrate and model energy use in China, an extensive dataset is needed. Over the last summer, we have put two Chinese-fluent researchers in the field to collect this kind of information on the electricity sector. The main data components are summarized in the following table:

Table 4.1: Data Resources for Electricity Sector Modeling

1. Fuel reserves/resource endowments (coal, natural gas, hydro, and wind)
2. Fuel extraction costs (e.g., average ratio of investment to output)
3. Power plant characteristics (age, efficiency, capacity factor)
4. Electricity costs (installed costs, O&M costs, fuel costs)
5. Coal heating values
6. Sulfur, carbon, and mercury content in coal

PANDA is currently calibrated with a combination of directly observed and imputed data values, but we have already identified the official sources needed to complete a direct calibration for the base year.

5. Water

5.1. Overview

Water availability and water quality will be increasingly prominent issues in the sustainable growth agenda for China. For this reason, policy makers will need better information about the structural implications of water allocation and water costs to support effective policy reform. Like land, water can be viewed as a classic factor of production and, again, subject to data availability, the PANDA can shed important light on interactions between water policy and the rest of the economy.

5.2. Previous Work

The research literature on water economics is very large and diverse, dominated by agricultural economics but with a significant sub-speciality in urban water use. For the present discussion, it is useful to focus on one geographic area where water research and water policy are especially advanced, California. As the world's fifth largest economy, combining a large and lucrative agricultural sector with several big urban areas, California presents many water policy challenges that are relevant to China. For example, California long ago committed to major infrastructure investments in water storage and long distance conveyance. These public works have made great contributions to overcoming seasonal and regional scarcity problems, and there is now a long record of data on the performance of these facilities.

Figure 5.1: Annual Rainfall is Limited

Figure 5.2: Major Irrigation Basins are in Overdraft
(source: CASS)

In addition to physical infrastructure, California has also developed extensive institutional systems for water management, including a globally innovative system of water markets (see Zilberman:2003). Like the dams and canal systems, these now have an established history of performance that can be instructive to other economies contemplating water reform. California also has a variety of water allocation models (Sunding et al:2002 provides a good review), many of which have been transplanted to other regions, but these deal mainly with practical allocation and management at the district level.

5.3. PANDA's Current Specification

To study the economics of water at the national level, the PANDA model introduces this resource as a classical factor of production and consumption good. Water comes in to types, Rural and Urban, where the latter are understood to be treated water and the former include free-running and subterranean water resources throughout the country. In production, both types of water are available to every sector of the economy, and can be used in combination with each other and other factors in the usual CES value added specification. Water quality in production is captured by sector and type specific productivity coefficients. This quality/productivity factor can in turn depend on environmental variables like pollution levels and water treatment capacity constraints, but these specification choices will depend on the policy question under study.

To capture water's diverse roles in the economy the two types are convertible according to a CET transformation (water treatment, recycling, etc.) function as follows:

Denoting rural water supply by WR and urban supply by WU, total supply is modeled with the CET production frontier

$$Max(pwr \bullet WR + pwu \bullet WU) \quad \text{subject to}$$

$$WT = \left[g_r \lambda_r WR^{\omega} + g_u \lambda_u WU^{\omega} \right]^{1/\omega}$$

where pwr and pwu denote prices for rural and urban water and WT is aggregate demand. Analytically this yields the following reduced forms

$$WR = \gamma_r \left(\frac{pwt}{PW} \right)^{\nu} WT \qquad WU = \gamma_u \left(\frac{pwu}{PW} \right)^{\nu} WU \quad \text{where} \quad \begin{cases} \gamma_r = (g_r \lambda_r)^{-\nu} \\ \gamma_u = (g_u \lambda_u)^{-\nu} \\ \omega = \dfrac{\nu + 1}{\nu} \end{cases}$$

and

$$PW = \left[\gamma_r WR^{1+\nu} + \gamma_u WU^{1+\nu} \right]^{1/(1+\nu)} = \left(pwr.WR + pwu.U \right) / WT$$

denotes the price index of XP.

This specification provides an aggregate way to model water transformation needs for the national economy, particularly as these relate to urbanization and resource scarcity. The productivity (λ) terms allow for technological innovation in water sourcing, management, and treatment.

5.4. Data Requirements

Water resources are notoriously difficult to measure and water allocation difficult to model, yet this resource is essential in two areas of the economy: food production and urbanization. In agriculture, several major basins are already in overdraft and technology adoption will be essential to sustain regional and national food production.

Urbanization is intensifying per capita water use and exerting significant pressure on local, regional, and ultimately national resources.

In the present version of PANDA, we have initial estimates of water resources and use by sector and household type. For more extensive research, however, we want to invest in better data to calibrate the model so we can study these important trends.

6. Land

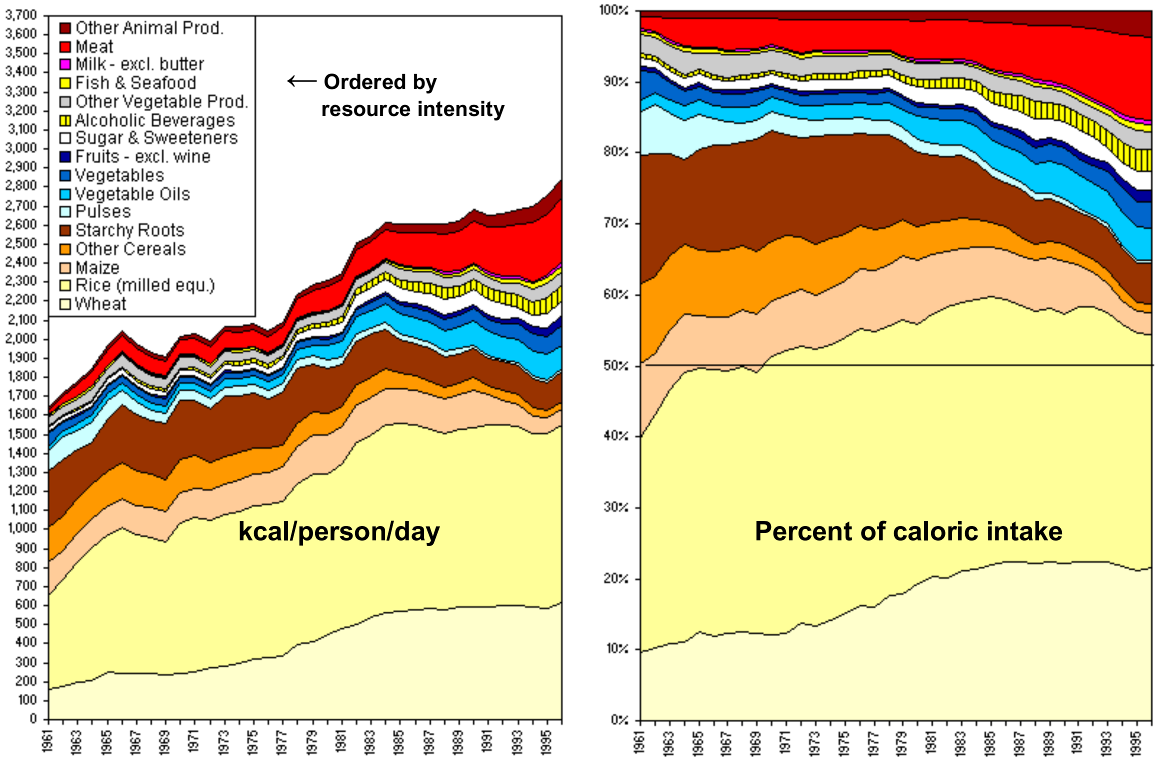
6.1. Overview

Land availability and use is one of the most pressing resource issues arising from China's dynamic growth experience. In the rural sector, the supply of arable land has long been constrained in per capita terms, and may have been shrinking in aggregate because of displacement, desertification, and unsustainable practices (Figures 6.1 and 6.2). At the same time, increasingly resource-intensive patterns of food demand are challenging China's agricultural productivity growth to maintain food security (e.g. Figure 7.1). In addition to agriculture, land is an essential factor of production for industry and service sectors, including residential services to households. Finally, it is an important determinant of wealth and as such plays important roles in financial markets and fiscal policy.

Figure 6.1: Arable Land is Relatively Scarce in China
(source: IIASA)

Figure 6.2: On a Provincial Basis, Arable Land Balances are Changing
(source: IIASA)

Figure 6.3: Changing Patterns of Chinese Food Demands



Allocation of this essential resource, between and within the rural and urban sectors, remains complicated by many legal and economic issues. For these and other reasons, it is essential for policy makers to understand the constraints and opportunities posed by alternative land availability scenarios. Subject to data availability, it would be very useful to develop scenarios for policy response to changing land resource conditions.

6.2. Previous Work

Land use is a vast research area, from geography and agronomy to urban planning and environmental sciences. In economics, there is a relatively recent and interesting literature on urbanization that informs our analysis. In the last two decades, the so-called Urban Sprawl literature has developed rapidly, with exponents like Glaeser (e.g. Glaeser and Kanh:2003), Henderson (Henderson et al:1995) arguing that large scale urbanization driven by transport economies and network externalities has contributed significantly to average productivity and real incomes in OECD countries, but also been associated with persistent inequality. A variety of authors have contributed to better understanding of the economic drivers of urbanization, while others have assessed the side effects on rural communities and transitional populations from population depletion, family dispersal, and market segmentation. The scope and diversity of this literature make it clear that better understanding of evolving land use is essential, particularly in a dynamic economy like China's, but we must begin with a concrete framework for assessment.

6.3. PANDA's Current Specification

In the present version of PANDA, land is characterized as a factor of production that comes in two types, Rural and Urban. As expected, Rural land dominates the agriculture sector and Urban land is primarily allocated to industry and service sectors. Exceptions to this general rule include peri-urban agriculture and rural services, but every sector has the potential to use both types of land, despite a relatively low substitution rate.

Initial land use data can be used to calibrate the base year allocation of land, but over time it is essential to model urbanization. In the current version of PANDA, this is done by specifying a version of the Harris-Todaro migration model, using relative land prices as the determining variables. Formally, this specification of inter-period land use changes follows that of labor migration in the prototype CGE as follows

$$T^s_{Rur} = (1-\delta_T)T^s_{Rur,-1} - TU$$

$$T^s_{Urb} = T^s_{Urb,-1} + TU$$

$$T^s_{Tot} = \sum_{Rur,Urb} L^s_\tau$$

$$TU = \chi^T \left(\frac{pt_{Urb}}{pt_{Rur}}\right)^{\omega^m} \quad \text{if} \quad \omega^m \neq \infty$$

where T_k denotes land of type k, TU denotes land transformed by urbanization, pt is the price of land, and other parameters are estimated from calibration or independent data. The δ parameter refers to annual reductions in arable land at the rural margin.

This factor can be positive (in the case of, e.g. desertification) or negative (land reclamation).

Land is thus specified for use in every sectoral economic activity and by each household type, whether as an asset or a capital good. In production, it is a factor in the traditional sense, and the model contains sector and type-specific productivity parameters to capture issues such as land degradation and returns to sustainable agricultural practices. Linkages between land productivity and other variables, such as agrochemicals and irrigation technologies, can be incorporated directly into this framework.

6.4. Data Requirements

Like water, land is a difficult resource to calibrate, yet is plays an essential economy role in three areas: agriculture, commercial development, and residential services. It is also an important determinant of individual and institutional wealth, and plays a critical role in financial markets and fiscal policy. The data in this area are imperfect, but we want to work with NBS and other sources to improve it.

The basic requirement for initial conditions is Rural and Urban land stocks in use by each sector and household type. We are already working with initial estimates of these, but they could be refined in consultation with NBS and line ministries.

7. Modelling Allocation Mechanisms

By definition, the primary allocation mechanism in CGE model specifications is price-directed, market mediated, and usually governed by neoclassical assumptions of perfect competition, profit maximization, etc. In contrast to this, many important resources in China are allocated by complex combinations of institutional administration and in the presence of significant market distortions. Among the more important resources in this category are land, water, and coal, all of which are focal points of long term growth and sustainability policy. For these reasons, PANDA has been designed to incorporate a universe of mechanisms which can simulate existing and hypothetical alternative allocation rules and mechanisms. These alternatives will vary with the resource and policy scenario under consideration, but for the present we provide a few illustrative examples.

7.1. Coal Allocation

Coal is by far the dominant energy source in China, and it will continue in this position for the foreseeable future (see e.g. Figure 7.1 below). Because of its relatively low cost, this fuel can facilitate China's rapid economic growth. This fuel has environmental characteristics, however, that pose a challenge to its use with conventional technologies, and planning for sustainable growth in China will necessarily include commitments to cleaner and more fuel efficient coal technology. Economically accessible coal reserves are also very unequally allocated across China, concentrated mainly in two northern provinces with limited industrial development and population density. Because of its prominence in China's fuel mix, unequal initial distribution, and physical characteristics, coal allocation is a costly, resource intensive, and institutionally complex process. Although coal is traded at the enterprise level, there is extensive local, provincial, and national government intervention in the allocation system. For exporting provinces, coal tariffs are an important fiscal resource. For the national government, coal allocation is an essential strategic consideration in both aggregate and regional growth policy. At the local level, there is extensive anecdotal evidence of rent-seeking in coal allocation.

Figure 7.1: Energy Inputs for Electricity Generation
Beijing 1995-2003

A national or even provincial level CGE model cannot effectively simulate all these institutional details, nor would the data necessarily be available to support this. It is essential, however, to depart from free market assumptions about this resource. Like all fuels in PANDA, coal is treated as a factor of production. In a traditional CGE, this would mean extreme assumptions about inter-sectoral mobility (either costless or immobile) and total supply (exogenous growth rate or investment driven capital accumulation). In reality, coal is neither sector specific nor perfectly mobile. Moreover, its aggregate supply is governed a combination of price sensitive investments (exploration and extractive capital accumulation) and regulatory oversight (usually constraining, related to safety, environment, etc.).

As a first approximation to modeling coal allocation, we use a multinomial CET specification, conveniently visualized as a production possibility frontier with dimension equal to the number of coal using sectors/households. To state this formally, we use a summary of the general CET formulation set out in van der Mensbrugghe (2005). Consider allocation of the resource in question, where coal is denoted by X_i allocated across i=1,…,n sectors. This allocation can be described formally as a solution to the boundary value problem

$$\max \sum_i P_i X_i$$

subject to

$$V = \left[\sum_i g_i X_i^{\nu} \right]^{1/\nu}$$

where V is the aggregate supply of the resource , the P_i denote corresponding allocation prices, g are the CET (primal) share parameters, and ν is the CET aggregator exponent. The CET exponent is related to the CET transformation elasticity, ω, via the following relation:

$$\nu = \frac{\omega + 1}{\omega} \Leftrightarrow \omega = \frac{1}{\nu - 1}$$

Solution of this boundary value problem leads to the following first order conditions:

$$X_i = \gamma_i \left(\frac{P_i}{P} \right)^{\omega} V$$

$$P = \left[\sum_i \gamma_i P_i^{1+\omega} \right]^{1/(1+\omega)}$$

where the γ parameters are related to the primal share parameters, *g*, by the following formula:

$$\gamma_i = g_i^{-\omega} \Leftrightarrow g_i = \left(\frac{1}{\gamma_i} \right)^{1/\omega}$$

The special case of infinitely elastic (linear) transformation implies a unique economywide resource allocation price,

$$P_i = P$$

and no efficiency losses, i.e.

$$V = \sum_i X_i$$

Finally, because coal is modeled in PANDA as a factor of production, its total supply must be linked to an extractive sector, where V=F(K,L,…) is output from a standard production sector in the CGE model.

This formulation is very parsimonious, yet it reflects important transactions cost characteristics of the allocation process. The empirical step from detailed institutional causes to more aggregate allocation frictions is a large one, but it can be supported with more detailed econometric estimation. As a second-order approximation it would make sense to consider estimating asymmetries in the allocation frontier, depending upon observed differences in unit allocation costs across sectors and households in the economy. This is data-intensive estimation work, but we believe it is preferable to maintaining a very detailed institutional specification in the model, particularly when most of the institutions under consideration are experiencing significant dynamic adjustment of their own.

7.2. Water Allocation

Allocation of water differs from other resources for two primary reasons: use characteristics and physical properties. Water use is relatively unique in agriculture because a large part of inter-sectoral mobility is not governed by physical location but by farm production decisions about which products to produce. Thus an individual agricultural enterprise, village, or region can change its patterns of supply across agricultural sectors, and with this water inputs to wheat, corn, livestock, etc., without "moving" in a physical sense. Despite this, changes in land use and cropping patterns can still entail technological change and transactions costs that limit water "substitution" across these activities. The second aspect of water, its physical characteristics, implies that sectoral mobility often requires investments in conveyance technology.

As a first approximation to these frictions in the water allocation system, we can use the multinominal CET framework set forth above. Note, however, that this would be in addition to the aggregate binomial CET that governs conversion from Rural to Urban water. For this reason, two multinominal CETs must be estimated, one for each type. Unlike coal, water is not produced by a sector of the economy (utilities are modelled in the CET conversion and allocation process), so aggregate water supplies are characterized by a functional form $W(\cdot)$ that depends on climate conditions, prices (for extractive water), and recycling costs.

7.3. Land Allocation

8. Summary

The PANDA model represents new capacity for Chinese policy research, integrating energy, resources, and environment in a long term, general equilibrium simulation framework. The model adapts a standard dynamic CGE to include emissions of a variety of important pollutants, detailed treatment of the energy sector, and explicit treatment of land and water use. Building on a new 2004 SAM to include the high levels of detail on sectoral supply, demand, employment and resource use, PANDA offers an up-to-date picture of the Chinese economy available, packaged in a long term policy simulation framework. In coordination with World Bank long term global projections, this domestic model can shed new light on China's growth and trade horizons.

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