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Prefectural Representation of the Regions of China in a Bottom-up CGE Model: SinoTERM365

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We create an applied general equilibrium database that represents 162 sectors in 365 prefectural regions of the Chinese economy. Our approach requires relatively modest data requirements to create a multi-region, sub-national database and extends methods used in The Enormous Regional Model (TERM). We call the new database 'SinoTERM365'. Where the database structure allows for more information than is available, we use simple assumptions to supply the deficiency. However, we hope that model users may collaborate to find more or better data. An illustrative simulation shows the long-run effects of a switch from coal to hydro electricity generation.

JEL codes: C68,D58, O13.

Keywords: Applied general equilibrium; China; Regional economic modeling.

1. Introduction

Sub-national multi-regional applied general equilibrium (AGE)¹ modelers confront the problem that most available sub-national input-output (IO) or supply-use databases at the regional level are highly aggregated. Moreover, practitioners are often interested in scenarios that involve only part of a province or state and one or two industries that are not well represented in the coarse sectoral representation of most regional databases. Economic activity within a province or state may be dominated by one or two large cities. The appetite for regional modeling often involves finer levels of sectoral or regional representation than are depicted in provincial or state databases. In particular, small region representation may enhance natural resource modeling. This paper explains a

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¹ Applied general equilibrium (AGE) and computable general equilibrium (CGE) are interchangeable terms.

methodology for meeting this demand, by devising a multi-regional AGE model depicting small regions, with comprehensive links between regions.

We call our methodology for depicting small regions in considerable sectoral detail in a multi-regional AGE model the (The Enormous Regional Model) TERM approach. The TERM methodology includes (1) a package of routines to generate sub-national, multi-regional databases, and (2) sub-national, multi-regional AGE models. We use this approach to devise a 162 sector, 365 region master database for China. This represents a challenge, as data at the small region level are not as abundant for China as for many other nations. Other countries have census data with considerable sectoral detail at the small region level to supplement existing national accounts data. Freely downloadable resources based on the TERM approach are listed in the conclusion. Examples cover China and other nations. Readers interested in gaining familiarity with SinoTERM365 or its predecessors can access materials via the link provided in Table 10, which all provides access to the database generation files. Those who wish to work with or contribute to ongoing SinoTERM365 development can contact the authors at the Centre of Policy Studies (see [tpgw0712](#) at the Table 10 link or email glyn.wittwer@vu.edu.au).

Section 2 outlines the procedure of data collection, multi-regional database generation and database aggregation for policy simulations using the TERM approach. Section 3 includes the first comprehensive description of the core theory of TERM models, working through the levels equations and model code. A stylized simulation is presented in Section 4. Supplementary files enable the reader to reproduce the simulation. The article concludes with section 5.

2. A method for devising a highly disaggregated, multi-regional, sub-national model

2.1 Previous efforts at sub-national representation

IO modelers have been analyzing economic activity in small regions for decades. One method is to use regional activity shares based on census data to estimate regional flows based on the IO table. The Economic Impact Analysis for Planning (IMPLAN) group devises tables for US state, city and county regions that appear to make substantial use of census data. This provides both the sectoral resolution and small region detail we aim for with the TERM approach, but lacks detailed links to other regions. Moreover, the framework lacks the economic theory of AGE models, so that resource constraints are imposed in an ad hoc manner rather than through consistent theory. And, despite the sectoral detail present in such tables, there is still a shortage of detail in sectors such as agriculture and electricity. AGE models with desirable sectoral disaggregation of the US economy include USAGE-TERM, with 70 regions and 500+ sectors in the master database (Wittwer 2017), and the state-level open access National Open source

Tools for general Equilibrium analysis (blueNOTE) package (see <https://aae.wisc.edu/blueNOTE/> and Rutherford and Schreiber, 2018).

Other examples of IO tables include inter-regional linkages. In China, Mi et al. (2017) devised a full multi-regional use matrix inclusive of inter-regional trades for 30 sectors in 30 regions. Yamada (2015, table 1) provides a table of various multi-regional IO tables for Japan. The largest number of sectors represented in Japan for all 47 prefectures is 59.

Typically, agriculture, mining and manufacturing are each represented by little more than a single sector in regional tables. The authors' checks on China's provincial tables indicate that they often do not sum reasonably to totals in the national table. This is not surprising, given that regional statistical bureaus prepare regional tables, with apparent limited harmonization between bureaus. But even with improved harmonization, a problem would remain, in that available regional IO tables do not take advantage of a great deal of regional data present in other sources. The TERM methodology is to make use of all available relevant data in preparing a multi-regional AGE database, and to allow for the possibility that as better data emerge, modelers can utilize it quickly in revising an AGE database.

2.2 Overview of the TERM approach

The TERM approach to devising a very detailed multi-regional sub-national AGE database starts with the national database. We disaggregate the official national IO or supply-use database into more sectors where we think it potentially useful. Next, we gather estimates of regional supply and regional demand shares of national activities at the small region level. Within the TERM suite of database generating programs, we devise value estimates of total regional supplies and demands. A modified version of the gravity assumption calculates estimates of inter-regional trade matrices. After running programs to balance the database, the master database is ready for use. In common with the Global Trade Analysis Project (GTAP) modeling approach, the master database is aggregated to preserve sectors and regions of interest in a particular scenario while reducing the dimensions of the database to a computationally manageable size for policy analysis.

Where data is lacking, simple assumptions can fill the gap. The aim is to develop a multi-regional application relatively quickly. Initial simulations often reveal data problems. Over time, new data sources may be found.

The first implementation of the TERM approach was to Australia (Horridge *et al.*, 2005).² Versions for other countries developed in succeeding years cover Brazil (Ferreira Filho and Horridge, 2006), Indonesia (Horridge *et al.*, 2006), Japan,³ China

² Wittwer and Horridge (2010) lists the equations of TERM but does not include the code shown in section 3 of the present paper.

³ See www.copsmodels.com/archivep.htm TPSY0054.

(SinoTERM at the provincial level, Horridge and Wittwer, 2008), USA (Wittwer 2017), South Africa,⁴ Finland (Törmä 2008; Simola *et al.*, 2011) and Poland (Zawalińska *et al.*, 2011).

2.2.1 Disaggregation of national database into more sectors

Sub-national regional IO or supply-use databases usually contain fewer sectors than national databases. The TERM approach is contrary to this for two reasons. First, disaggregation often simplifies data collection at the regional level. For example, we may know how much wheat is grown in a region and how much gold is produced, but we are less certain of the region's share of national agricultural or mining activity.

Second, with sectoral disaggregation we aim to improve the policy relevance and versatility of the multi-regional AGE framework. Many countries, including China, depict agriculture in national tables in two sectors, crops and livestock. A great deal of disaggregated data are usually available for small regions. In China, for example, provincial statistical yearbooks are reasonably comprehensive in their coverage of an array and crops and herd numbers for different animals at the prefectural level (see Table 2). Yet agricultural, forestry and fishing activities that still account for at least one quarter of national employment, are represented by a single sector in China's provincial IO tables. The advantage of depicting primary industries at the small region level is that it enables us to model an array of land and water allocation issues.

Some major policy issues that AGE modelers may wish to analyze require further splitting of sectors in official national IO tables. Adams and Parmenter (2013) and Adams (2003) detail different types of electricity generation at the state level in Australia. With different forms of generation within the model, estimates of carbon emissions are more accurate. Modeled responses to a carbon tax that induces changes in competitiveness among generators and modeled outcomes are more helpful to policy makers. There may be interest in disaggregating into smaller regions: electricity-generating stations are often located in clusters near coalfields. Decommissioning such plants will result in short-run local job losses, just as construction of wind or solar farms will result in additional short-run local jobs.

Away from major cities, health services are limited. Patients requiring specialist services may need to travel hundreds of kilometers for care. Sub-dividing the health sector in an AGE model may help depict the divide between major cities and more remote regions concerning health services. This usually requires detailed census data in either the industrial or occupational dimensions at the small region level.

⁴ See www.copsmodels.com/archivep.htm TPMH0126.

Disaggregation of sectors also assists estimation of inter-regional trade matrices in some instances. We assign activities as either local or traded at the small region level. For example, we treat elementary or primary schooling as strictly local (implying that the inter-regional trade matrix contains non-zeroes only on the diagonal), whereas higher forms of education are tradable between regions. Tertiary education is internationally traded. Suitable disaggregation enables modelers to analyze that otherwise would not be possible. For example, Waschik, et al. (2018) analyzed the economic impacts of regional universities in Australia.

2.2.2 Estimates of regional supplies and regional demands in small regions

We aim to devise small region representation in an AGE database because some of the most marked disparities in income and access to essential services are between regional capital cities and elsewhere in a province or state. In the example of Guangdong province in China, 2014 GDP per capita in Guangzhou city exceeded 130,000 RMB, whereas in Meizhou city, it was less than 20,000 RMB⁵ The SinoTERM365 representation includes 21 prefectures in Guangdong.

The strategy to deal with scarce sub-national regional data is to keep the data requirements modest while using a reproducible sequence of problems, into which inputs can be altered readily as improved data emerge. In the past, practitioners have often cited two constraints to regional modelling: the limited availability of regional IO tables; and an absence of inter-regional trade detail.

Ideally, at the small region level, data on farm outputs, employment by industry data from the census and supplementary data on electricity generation may be available.⁶ Since customs posts exist at international ports, international trade data by port are available for many countries.

2.2.3 Identical technologies

A key assumption in the TERM methodology is that an identical technology or input cost structure is imposed on a given industry in all regions. By disaggregating the national database at the outset, we reduce the burden of this assumption. For example, in China, hydroelectric generation dominates Sichuan's electricity generation, whereas coal-fired generation dominates Shanxi's generation. Given the differing composition of generation types between regions, it is inappropriate to assume that all regions have an identical single electricity generation technology. It is defensible to assume that coal-fired generation has the same technology in different regions, but not defensible to assume that coal-fired and hydropower generation have identical technologies. In the case of known

⁵ The data source is the Guangdong Statistical Yearbook, no longer available through the University of Michigan online.

⁶ The website carma.org detailing 50,000 power stations globally has been discontinued due to web security concerns (personal communication).

differences in technologies between regions, we prepare different industries in the national database to reflect different technologies.

2.2.4 Strategy to reduce simulation times

We deal with the first problem of slow simulations through two broad strategies, which are in common with the GTAP approach. First, several multi-dimensional database matrices are partitioned into two smaller matrices. As in the GTAP Data Base, the intermediate and final use matrices (a single matrix in the TERM format) include the regional user but not the regional origin. The trade matrices include the regional origin and regional destination but not the user. The small cost that comes with the common sourcing assumption is that the use matrices added up over users must equal the trade matrices summed across regional origins. The separation of full data dimensions into two matrices distinguishes TERM from Australia's Victoria University-Regional Model (VURM) (Adams et al. 2011), as it distinguishes GTAP (Corong et al., 2017) from its predecessor SALTER ((Sectoral Analysis of Liberalising Trade in the East Asian Region) (Jomini, et al. 1994).

To illustrate the saving of using two matrices instead, consider a model in which there are 20 commodities, 20 industries, 4 final users and 20 sub-national regions plus imports. We assign a domestic and imported subscript to each origin so as to identify international port activity within the model. A use matrix identifying commodities (20), origins (20 x 2, i.e., domestic/imported), destinations (20), intermediate (20) plus final users (4) would contain 384,000 cells (=20x20x2x20x24). If we partition the data into a USE matrix excluding regional origins (20 commodities, 2 domestic/imported origins, 20 destinations and 24 users), with 19,200 cells and a TRADE matrix excluding users (20 commodities, 20 x 2 origins, 20 destinations) with 16,000 cells, the two matrices sum to 9.2% the size of a matrix that includes all relevant dimensions. The market clearing identity that enforces the two matrices to be equal will contain 800 cells (=20 commodities x 2 sources x 20 destinations), adding only a few percent to database size.

In practice, a second strategy in common with that of GTAP model users, is to aggregate sectors and regions of little or no interest in a scenario while maintaining detail in sectors and regions of interest. This lowers the computational times for modelers.

2.2.5 Canadian provincial supply-use tables: the case of abundant data

Do cases of IO tables which are highly disaggregated in the sectoral dimension, and with estimates of inter-regional trades, render the TERM approach redundant? The most detailed sub-national multi-regional supply-use tables known to the authors are those prepared by Statistics Canada. These tables depict the sales of 446 commodities to 187 industries plus final users in 14 provinces/territories. Statistics Canada puts much effort into estimating

international trades between sub-national regions and the rest of the world and inter-regional trades between provinces/territories. Many data sources are used in the estimation effort, including producer surveys, wholesale trade surveys and services surveys (UN, 2018).

Statistics Canada uses around 50 staff to main their supply-use tables for 14 regions plus the national tables (UN, 2018). No other statistical agency has made this level of commitment to the provision of such data. In the sectoral dimension, Statistics Canada match or exceed our desired detail in agriculture, mining, health, education and other sectors. The only segment in which we would seek more detail is in depicting different forms of electricity generation, as a single sector covers all generation, transmission and distribution.⁷

The regional dimension is a different matter. We regard the Canadian data as an incomparable starting point for a potential disaggregation into smaller regions, so as to capture economic activities in regional centers that may be many hundreds of kilometers from the provincial capital. Canada has approximately 200 census divisions, which would be a feasible level at which to estimate regional activities, based on a combination of provincial tables, census division employment data and some sector-specific sources such as mining statistics.

2.3 Preparing the SinoTERM365 database

TERM offers a strategy in stark contrast to that of practitioners who believe that both regional IO tables and some inter-regional trade are necessary to devise a multi-regional AGE database. The SinoTERM365 database has been estimated from very limited regional data, even more scarce than the data typically used by TERM practitioners.

Our technique of combining a national IO table with limited regional data to produce a detailed inter-regional table bears many similarities to methods developed over several decades by regional IO modelers. Indeed, published regional IO tables may well be in part constructed rather than observed. Unfortunately, the method of construction may be poorly documented or unrepeatable. The TERM data programs are downloadable and may be customized to suit particular needs (see Table 14).

2.3.1 Preparation of national database for China

In China as elsewhere, regional data are often available for sectors with more detail than in the national IO table. Beijing's National Bureau of Statistics appears to have followed international convention in providing limited detail on agriculture in the national IO table, a convention that the GTAP Data Base creators

⁷ Our inspection of the Statistics Canada supply-use tables suggests that their default assumption, common with the TERM approach, is that each industry uses an identical technology in all regions.

from the beginning wisely chose not to follow. The official Chinese IO table includes a single crops sector, a single livestock sector and another sector covering services to agriculture. We know that climate, water availability and types of crop vary widely across China. Moreover, even with rapid structural change, around 25% of China's workforce (equal to 5% of the global workforce) is still employed in agriculture. Given that land and water availability is a major policy issue, we split the single crop sector from the available IO table into 14 (i.e., rice, wheat, corn, other cereals, soybeans, tubers, other vegetables, cotton, sugar cane, tea, apples & pears, citrus, grapes and other crops) and the single livestock sector into three (pigs, sheep & goats, other livestock). China accounts for one quarter of global meat consumption (Myers, 2016): the meat sector is split into two to separate pork from other meat types. Available data may provide good estimates of a region's share of national output of the 14 crops we have chosen to represent. Similarly, herd numbers and other statistics are available for various types of livestock.

The other split is of the electricity sector into 7 forms of generation plus a sector for transmission and distribution. The different generation forms are coal-fired, gas-fired, other thermal, nuclear, hydroelectric, wind and solar. Regional estimates rely heavily on data prepared by the Center for Global Development for 50,000 power stations across the globe.⁸

2.3.2 Estimates of the regional distribution of output and final demands

The first version of SinoTERM (Horridge and Wittwer, 2008; Wittwer and Horridge, 2009) represented the 27 provinces and 4 municipalities of China separately. The new version, SinoTERM365, relied on China Data Center, University of Michigan (accessed via the National Library of Australia) as the main source for prefectural level data. In particular, the site provided access to provincial statistical yearbooks. Unfortunately, the University of Michigan's resource is no longer accessible, ostensibly because it is no longer cost effective (Leung 2018).

The census data used to estimate regional activity shares in the Australian TERM (Wittwer and Horridge, 2010) and USA TERM (Wittwer 2017) databases cover hundreds of sectors, whereas Chinese census data cover only 19 sectors. This means that such data are less specific in estimating regional activities in manufacturing and services sectors than in the USA and Australia. The available broad industry census employment numbers for China provide some measure of prefecture-level economic activity. At worst, this means that broad sector outputs (outside of agriculture, for which data are sufficient in most provinces) are split between the disaggregated sectors of the national database in identical

⁸ The website carma.org from which we downloaded data on the location, capacity and emissions of power generation stations has been discontinued due to cyber-security concerns (Center for Global Development, personal communication).

proportions across all prefectures in a given province. In addition, census data available to the authors for a number of provinces are only for 2005 (Table 2), whereas the base year of the national IO table is 2012.

For some commodities, we were able to improve on yearbook data. For example, the Liaoning province yearbooks includes employment for a single manufactures sector. An online search indicates that within Liaoning, only Dalian and Shenyang produce motor vehicles (as distinct from the separate motor vehicle parts sector), so activities for this sector in other prefectures within the province are set to zero. Prefectural level data are also available for meat products. But in remaining manufactures, the broad manufacturing employment shares provide the sub-provincial split.

Table 1 shows the sectoral detail in the SinoTERM365, national and provincial IO tables and, if available at the prefectural level, employment.

Table 1. SinoTERM365, national IO, provincial IO and employment data representation

| Sector group | SinoTERM365 2012 | National IO 2012 | Provincial IO 2012 | Prefectural employment ^a |
|-----------------------------------|---------------------|---------------------|-----------------------|--|
| Primary | | | | |
| Crops | 14 | 1 | | |
| Livestock | 3 | 1 | | |
| Fishing, forestry & agri. srv. | 3 | 3 | 1 | 1 |
| Mining | 6 | 6 | 4 | 1 |
| Manufactures | | | | |
| Food & tobacco | 15 | 14 | 1 | |
| TCFs | 8 | 8 | 2 | |
| Fuel & chemical | 11 | 11 | 2 | |
| Non-metal min prods | 7 | 7 | 1 | |
| Metals | 6 | 6 | 2 | 1 |
| Machinery | 10 | 10 | 1 | |
| Transport Eqp | 5 | 5 | 1 | |
| Electrical & electronic | 12 | 12 | 3 | |
| Oth manufactures | 11 | 11 | 3 | |
| Other | | | | |
| Utilities | 10 | 3 | 2 | 1 |
| Construction | 4 | 4 | 1 | 1 |
| Services | 37 | 37 | 6 | 14 |
| Total | 162 | 139 | 30 | 19 |

Notes: (a) In prefectural level national accounts data, mining, manufacturing and utilities are combined into a single sector. Otherwise, the employment (19) and national accounts (17) sectors are the same.

Source: Authors calculations

Table 2. Summary of prefecture-level data

| | No. of regions | Agriculture (2013 or later) | Manufacturing output (2013 or later) | Employment or national accounts data (19 sectors if not stated) ^b |
|--------------|----------------|-----------------------------|--------------------------------------|--|
| Hebei | 11 | Complete | | 2005 census |
| Shanxi | 11 | Complete | 14 sectors | 2014 6 sectors |
| InnrMongolia | 12 | Complete | 9 sectors | 2005 census |
| Liaoning | 14 | Complete | | 2013 |
| Jilin | 9 | Complete | | nat ac 17 sectors |
| Heilongjiang | 15 | Complete | | nat ac 17 sectors |
| Jiangsu | 13 | 1 agri. sector | 30 sectors | 2005 census |
| Zhejiang | 12 | Complete | | 2005 census |
| Anhui | 16 | Complete | | 2013 |
| Fujian | 9 | 5 agri. sectors | | 2005 census |
| Jiangxi | 11 | Complete | 18 sectors | 2005 census |
| Shandong | 17 | Complete | | 2014 |
| Henan | 18 | Complete | 24 sectors | 2014 |
| Hubei | 17 | Complete | | Broad sector (5) only |
| Hunan | 14 | 4 agri. sectors | | nat ac 17 sectors |
| Guangdong | 21 | Complete | | 2005 census + 2014 |
| Guangxi | 14 | 10 agri. sectors | | 2005 census |
| Hainan | 18 | 7 agri. sectors | 20 sectors detailed | 2014 |
| Chongqing | 5 | 7 agri. sectors | | Broad sector (5) only |
| Sichuan | 21 | 11 agri. sectors | | 2005 census |
| Guizhou | 9 | 5 agri. sectors | | 2005 census |
| Yunnan | 16 | Complete | | 2014 |
| Tibet | 7 | Complete | | 2014 |
| Shaanxi | 11 | Complete | | 2005 census |
| Gansu | 14 | Complete | | 2014 |
| Qinghai | 8 | Complete | | 2005 census |
| Ningxia | 5 | Complete | | 2005 census |
| Xinjiang | 14 | Complete | Meat only | 2014 14 sectors |

Notes: nat ac — national accounts; (a) Beijing, Tianjin and Shanghai are each represented by a single region in SinoTERM365. (b) The file mappings.har within online materials accompanying this paper incudes mappings to the 162 sectors of the master database.

Source: National Bureau of Statistics of China.

The provincial IO tables have two main uses. The first is to provide value-added control totals as above, so that we scale the estimates of 162 sectoral activities for each prefecture to sum to 30 sectoral provincial activities. Without the IO table, we would default to 17 national accounts sectors at the provincial level for control totals. The other use of provincial IO tables is to provide provincial level targets for aggregate household consumption, public consumption and investment. Using either reported or estimated prefectural GDPs, we can allocate provincial shares implied by regional IO tables to the prefectural level.

International trade shares in the database are calculated from available information on port activities or, if available, customs data. In the case of merchandise, non-zero shares are limited to ports involved in international trade. For services, we may set export shares initially to regional output shares. We may base international services imports on prefectural aggregate demands. If we know more about international service trade shares, for example from regional university enrolments, we can improve on the shares we use as starting points.

2.3.3 The TRADE matrix

Using regional supply and final use shares, we generate regional activity levels by splitting the national AGE database. The next stage is to construct a TRADE matrix. For each commodity either domestic or imported, TRADE contains a 365x365 submatrix, where rows correspond to region of origin and columns correspond to region of use. Diagonal elements show production which is locally consumed. We already know from regional shares used to split the national database both the row totals (supply by commodity and region) and the column totals (demand by commodity and region) of these submatrices. We use the gravity formula (trade volumes follow an inverse power of distance) to construct trade matrices consistent with pre-determined row and column totals. In defence of this procedure, note that wherever production (or, more rarely, consumption) of a particular commodity is concentrated in one or a few regions, the gravity hypothesis is called upon to do very little work. Because our sectoral classification is so detailed, this situation occurs more frequently than with a relatively aggregated sectoral dimension.

The usual TERM gravity formula, as described in Horridge (2011) is:

$$\frac{V_{r,d}}{V_{\bullet,d}} \propto \frac{\sqrt{V_{r,\bullet}}}{D_{r,d}^k} \quad r \neq d \quad (1)$$

where $V_{r,d}$ = value of flow from origin r to destination d , $V_{r,\bullet}$ = production in r , $V_{\bullet,d}$ = demand in d , $D_{r,d}$ = distance from r to d , where K is a commodity-specific parameter valued between 0.5 and 2, with higher values for commodities not readily tradable.

Diagonal cells of the trade matrices are set according to:

$$\begin{aligned} \frac{V_{d,d}}{V_{d,\bullet}} &= \text{locally-supplied demand in } d \text{ as share of local production} \\ &= \min \left\{ \frac{V_{d,\bullet}}{V_{\bullet,d}}, 1 \right\} F \end{aligned} \quad (2)$$

where F is a commodity-specific parameter valued between 0.5 and 1, with a value close to 1 if the commodity is not readily tradable. The initial estimates of

$V(r,d)$ are then scaled using a residual allocation system (RAS) procedure so that $\sum_r V(r,d) = V(\bullet,d)$ and $\sum_d V(r,d) = V(r,\bullet)$. Transport costs as a share of trade flows are set to increase with distance, $T(r,d)/V(r,d) \propto \sqrt{D(r,d)}$

where $T(r,d)$ corresponds to margins on the TRADE matrix (TRADMAR in Section 3, Table 12). Again, the constant of proportionality is chosen to satisfy constraints derived from the initial national IO table.

All these estimates are made with the fully-disaggregated database. In many cases, zero trade flows (i.e., local sectors) can be known a priori. At a maximum sectoral disaggregation, the load borne by gravity assumptions is minimized.

2.3.4 Aggregation

The master database of 162 sectors and 365 regions is far too large for simulations. The next stage in the data procedure is to aggregate the data to a more manageable size. The aggregation choice is application-specific. Our aggregation example is that of the simulation presented in section 4. This concerns a demand switch away from coal-generated electricity towards hydro-electric generation. The sectoral aggregation preserves the coal mining sector, coal-generated electricity, hydro-electric generation and electricity distribution from the master database, while reducing the number of sectors to 21. In the regional dimension, three prefectures in which coal accounts for a large share of regional GDP are represented individually (see Table 13). These are Erdos (Inner Mongolia), Shuoxhou (Shanxi) and Huaibei (Anhui). In each case, a regional composite covers the rest of the province. A seventh region is Shaanxi, in which coal accounts for a significant share of provincial GDP, and an eighth region the rest of China. The 365 regions of the master database are aggregated to 8 regions (Figure 1).

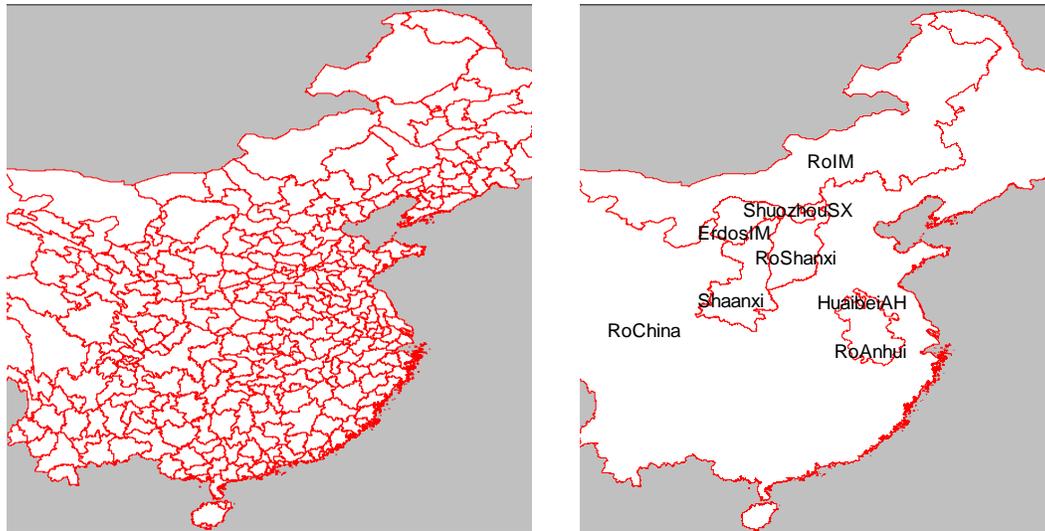


Figure 1. Aggregating from master database to policy simulation regions

2.3.5 Working with and improving deficient regional data

We use the example of Fujian province, for which the data are relatively limited, to show we how devise estimates in the absence of detailed data. Fujian's agricultural data cover only 5 sectors (Table 2). However, since Fujian's subtropical climate favors rice cultivation ahead of wheat or corn, we treat grains output as referring to rice only. The available data include tea (a sector within SinoTERM365), fruit and sugarcane at the prefectural level. We use the fruit outputs to devise identical prefectural shares for apples & pears and citrus. If we know respective outputs at the provincial level for these two fruit groups, we can scale the prefectural shares for each group accordingly. For the remaining agricultural groups, we may use proxies. Livestock shares may be based on available meat output for each prefecture. We may use prefectural employment shares for all of agriculture, forestry and fishing as proxies for remaining agricultural commodities.

Available data at the 19 sector level for each Fujian prefecture are based on the 2005 census. Typically, we have either prefectural total value-added or three sector (primary, secondary, tertiary) value-added totals at the prefectural level, which provide another set of targets for scaling. Unfortunately, we did not have even those three sector control totals for Fujian prefectures.

Aware of the limitations of the prefectural share estimates we have for Fujian, we proceed to the stage of generating a multi-regional AGE database. There are three broad approaches to maintaining and improving the regional database. The first is that through early generation of a database, we can discover problems at the regional level in the process of running and analyzing simulations focused on Fujian prefectures. Second, in collaboration with model users, we hope to improve our access to more detailed and more recent data. The third is that the TERM suite of programs (see Table 14) enables us to generate a new database rapidly as better data emerge. To make several changes to prefectural activity shares and regenerate a master database from the national database may take less than one hour.

3. The equations of TERM

The TERM suite of models follows the core theory elaborated in this section. The TERM methodology uses a set of database generating routines that are similar across all countries (see Table 14, TPMH0067). However, the user may modify programs to utilize more detailed sub-national data if they are available. Horridge et al. (2005) and Horridge (2012) describe the database methodology. This section elaborates the core theory of the TERM by presenting the levels version of each block of equations. Wittwer and Horridge (2010) present a previous outline of the core TERM theory; the present section explains the core theory comprehensively. The model is implemented using General Equilibrium Modelling Package (GEMPACK) software (Horridge et al., 2018). TABLO coding of the model's

equations follows each block – here most equations appear in log-linearized form. Multi-step solution methods (Dixon et al., 1982, chapter 5) enable the modeler to combine the accuracy of the levels form with the relative simplicity and computational speed of linearized equations.

3.1 Production

Each industry uses a combination of intermediate and primary inputs to produce a unit of output. Producer decisions consist of a sequence of constant-elasticity-of-substitution (CES) decisions, with a composite commodity entering the next stage. Figure 2 shows the production structure.

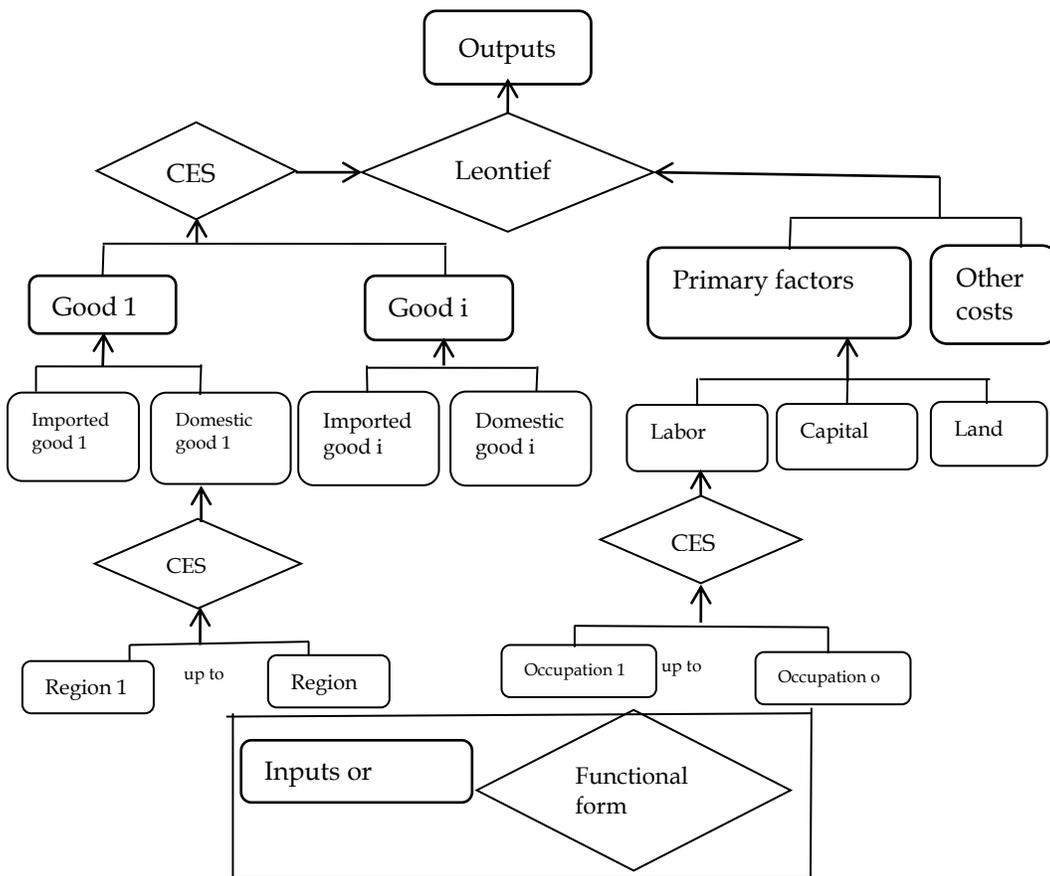


Figure 2. Production structure

Source: Authors' own figure.

Users of commodities minimize costs subject to CES substitutability:

$$X_{ud}^{cs} = f(X1_{ud}^c, CES[P_{ud}^{cs} / P1_{ud}^c]) \quad (3)$$

$$P1_{ud}^c \cdot X1_{ud}^c = \sum_s X_{ud}^{cs} \cdot P_{ud}^{cs} \quad (4)$$

X_{ud}^{cs} is the quantity demand of commodity c from (domestic composite or imported) source s by user u in region d . Users include industries plus final users (households, investors, exporters and government). P_{ud}^{cs} is the corresponding price, and $X1_{ud}^c$ and $P1_{ud}^c$ the respective domestic-import composite quantities and prices.

Throughout the TABLO notation in this section, the index c refers to commodities (COM), s to domestic or imported source (SRC), d to destination (DST), u to users (USR) and i to industry ($IND \in USR$).

Table 3: Definitions of variables, values and parameters in intermediate and final usage

| Variables | |
|--------------------------------------|---|
| xint(c,s,i,d) | Source-specific (dom./imp.) intermediate demands |
| xint_s(c,i,d) | Source-composite intermediate demands |
| xhou(c,s,d) | Source-specific (dom./imp.) household demands |
| xhou_s(c,d) | Source-composite household demands |
| xinv(c,s,d) | Source-specific (dom./imp.) investment demands |
| xinv_s(c,d) | Source-composite investment demands |
| ppur(c,s,i,d) | Source-specific (dom./imp.) tax-inclusive com. price for user |
| ppur_s(c,i,d) | Source-composite tax-inclusive commodity price for user |
| puse(c,s,u,d) | Source-specific (dom./imp.) commodity price for user |
| tuser(c,s,u,d) | Powers of commodity taxes |
| pint(i,d) | Intermediate effective price indices |
| pinvest(c,d) | Purchaser's price for investment |
| phou(c,s,d) | Household price |
| aint_s(c,i,d) | Intermediate tech change |
| Values, shares and parameters | |
| PUR_S(c,i,d) | Purchasers' values summed over sources |
| PUR_CS(i,d) | Purchasers' expenditure summed over commodities |
| SIGMADOMIMP(c) | CES parameter, domestic v. import sources |

Source: Authors' construction.

Listing 1 shows the percentage change quantity equations concerning equation (3) in TABLO format. 1 The indexes "hou" and "inv" refer to the household and investment elements of the user set.

¹ Note that the TABLO equation numbering follows that of previous equations in text: i.e., (T5) corresponds with (5).

Listing 1. Intermediate and final usage (partial GEMPACK coding)

```

xint(c,s,i,d)      = xint_s(c,i,d) -
SIGMADOMIMP(c) * [ppur(c,s,i,d) - ppur_s(c,i,d)];          (T3a)

xhou(c,s,d) = xhou_s(c,d) -
SIGMADOMIMP(c) * [ppur(c,s,"hou",d) - phou(c,d)];          (T3b)

xinv(c,s,d) = xinv_s(c,d) -
SIGMADOMIMP(c) * [ppur(c,s,"inv",d) - pinvest(c,d)];      (T3c)

ppur(c,s,u,d) = puse(c,s,d) + tuser(c,s,u,d);              (T4a)

PUR_CS(i,d) * pint(i,d) =
sum{c,COM,PUR_S(c,i,d) * [ppur_s(c,i,d) + aint_s(c,i,d)]}; (T4b)

pinvest(c,d) = ppur_s(c,"Inv",d);                           (T4c)
phou(c,d) = ppur_s(c,"hou",d);                               (T4d)

```

3.2 Commodity sourcing at the sub-national level

Users in a given region source from sub-national regions in common proportions, so that the user subscript is dropped from the equation for sub-national CES substitution:

$$XT_{rd}^{cs} = f(XT1_d^{cs}, CES[PD_{rd}^{cs} / PU_d^{cs}]) \quad (5)$$

$$PU_{sd}^c \cdot XT1_d^{cs} = \sum_r XT_{rd}^{cs} \cdot PD_{rd}^{cs} \quad (6)$$

The total demand for all users of commodity *c*, domestic or import source *s*, from sub-national origin *r* to destination *d* is XT_{rd}^{cs} . Sub-national source composite demands are denoted by $XT1_d^{cs}$ and user prices by $XT1_d^{cs}$. TERM substitutability possibilities involve two stages, between a domestic composite and imports, and between sub-national sources to form the domestic composite.

Table 4. Definitions of variables, values and parameters in trade

| Variables | |
|------------------------------|--|
| xtrad_r(c,s,d) | Total demand for regional composite |
| xtrad(c,s,r,d) | Quantity of commodity dom/imp commodity delivered from origin <i>r</i> to destination <i>d</i> |
| pdelivrd(c,s,r,d) | All-user delivered price of commodity <i>c</i> |
| Values and parameters | |
| DELIVRD(c,s,r,d) | Trade plus margins = delivered values |
| DELIVRD_R(c,s,d) | Demand in region <i>d</i> for delivered commodities summed over origins |
| SIGMADOMDOM(c) | CES parameter for substitution between origins |

Source: Authors' construction.

Listing 2. Inter-regional trade (partial GEMPACK coding)

$$\begin{aligned} \text{xtrad}(c, s, r, d) &= \text{xtrad}_r(c, s, d) \\ \text{SIGMADOMDOM}(c) & * [\text{pdelivrd}(c, s, r, d) - \text{puse}(c, s, d)]; \end{aligned} \quad (\text{T5})$$

$$\begin{aligned} \text{DELIVRD}_R(c, s, d) & * \text{puse}(c, s, d) = \\ \text{sum}\{r, \text{ORG}, \text{DELIVRD}(c, s, r, d) & * \text{pdelivrd}(c, s, r, d)\}; \end{aligned} \quad (\text{T6})$$

Next, we outline cost minimizing behaviour in primary factor demands by industry users. The occupation o mix of labor follows a CES form:

$$L_{id}^o = f(L1_{id}, \text{CES}[W_{id}^o / W1_{id}]) \quad (7)$$

$$W1_{id} \cdot L1_{id} = \sum_o L_{id}^o \cdot W_{id}^o \quad (8)$$

Occupation-specific labor demands are L_{id}^o and labor composite demands $L1_{id}$ with the corresponding wages being W_{id}^o and $W1_{id}$.

$$L1_{id} = f(F_{id}, \text{CES}[W1_{id} / PF_{id}]) \quad (9)$$

$$LND_{id} = f(F_{id}, \text{CES}(RLND_{id} / PF_{id})) \quad (10)$$

$$K_{id} = f(F_{id}, \text{CES}(R_{id} / PF_{id})) \quad (11)$$

$$PF_{id} \cdot F_{id} = LND_{id} \cdot RLND_{id} + L1_{id} \cdot W1_{id} + K_{id} \cdot R_{id} \quad (12)$$

Equations (9) to (12) show primary factor demands for the labor composite $L1_{id}$, capital K_{id} and land LND_{id} subject to a composite factor demand F_{id} by industry i in region d . The factor prices are $W1_{id}$ for composite labor, R_{id} for capital rentals, $RLND_{id}$ for land rentals and PF_{id} for composite prices.

Listing 3. Primary factor demands (partial GEMPACK coding)

$$\begin{aligned} \text{xlab}(i, o, d) &= \text{xlab}_o(i, d) - \\ \text{SIGMALAB}(i) & * [\text{plab}(i, o, d) - \text{plab}_o(i, d)]; \end{aligned} \quad (\text{T5})$$

$$\begin{aligned} \text{LAB}_O(i, d) & * \text{wlab}_o(i, d) = \\ \text{sum}\{o, \text{OCC}, \text{LAB}(i, o, d) & * [\text{plab}(i, o, d) + \text{xlab}(i, o, d)]\}; \end{aligned} \quad (\text{T6a})$$

$$\text{LAB}_O(i, d) * \text{plab}_o(i, d) = \text{sum}\{o, \text{OCC}, \text{LAB}(i, o, d) * \text{plab}(i, o, d)\}; \quad (\text{T6b})$$

$$\begin{aligned} \text{xlab}_o(i, d) - \text{alab}_o(i, d) &= \text{xprim}(i, d) - \\ \text{SIGMAPRIM}(i) & * [\text{plab}_o(i, d) + \text{alab}_o(i, d) - \text{pprim}(i, d)]; \end{aligned} \quad (\text{T7})$$

$$\begin{aligned} \text{xln}(i, d) - \text{alnd}(i, d) &= \text{xprim}(i, d) - \\ \text{SIGMAPRIM}(i) & * [\text{plnd}(i, d) + \text{alnd}(i, d) - \text{pprim}(i, d)]; \end{aligned} \quad (\text{T8})$$

$$\begin{aligned} \text{xcap}(i, d) - \text{acap}(i, d) &= \text{xprim}(i, d) - \\ \text{SIGMAPRIM}(i) & * [\text{pcap}(i, d) + \text{acap}(i, d) - \text{pprim}(i, d)]; \end{aligned} \quad (\text{T11})$$

$$\begin{aligned} \text{PRIM}(i, d) * \text{pprim}(i, d) &= \text{LAB}_O(i, d) * [\text{plab}_o(i, d) + \text{alab}_o(i, d)] \\ + \text{CAP}(i, d) & * [\text{pcap}(i, d) + \text{acap}(i, d)] \\ + \text{LND}(i, d) & * [\text{plnd}(i, d) + \text{alnd}(i, d)]; \end{aligned} \quad (\text{T12})$$

Table 5. Definitions of variables, values and parameters in primary factor demands

| Variables | |
|------------------------------|---|
| xlab(i,o,d) | Labor demands, occupation specific |
| plab(i,o,d) | Wage rates, occupation specific |
| xcap(i,d) | Capital usage |
| xlnd(i,d) | Land usage |
| pcap(i,d) | Rental price of capital |
| plnd(i,d) | Rental price of land |
| plab_o(i,d) | Price of labor composite |
| xlab_o(i,d) | Effective labor input |
| wlab_o(i,d) | Wage bills |
| alab_o(i,d) | Labor-augmenting technical change |
| acap(i,d) | Capital-augmenting technical change |
| alnd(i,d) | Land-augmenting technical change |
| xprim(i,d) | Primary factor composite |
| pprim(i,d) | Effective price of primary factor composite |
| Values and parameters | |
| LAB(i,o,d) | Wage matrix |
| CAP(i,d) | Rentals to capital |
| LND(i,d) | Rentals to land |
| LAB_O(i,d) | Total labor bill in industry i |
| PRIM(i,d) | Total factor input to industry i |
| SIGMAPRIM(i) | CES parameter, primary factors |

Source: Authors' construction.

The composite factor demand F_{id} is proportional to total output Q_{id} subject to a primary-factor using technology A_{id} .

$$F_{id} = Q_{id} \cdot A_{id} \quad (13)$$

The demand $X1_{id}^c$ is related to output Q_{id} by a CES relationship between the composite price $P1_{id}^c$ and the price composite of all intermediate commodities $P11_{id}$. The CES is assumed to be 0.15 (i.e., weakly substitutable).

$$X1_{id}^c = f(Q_{id}, CES[P1_{id}^c / P11_{id}]) \quad (14)$$

$$P11_{id} \cdot X11_{id} = \sum_c P_{id}^c \cdot X1_{id}^c \quad (15)$$

The zero pure profit condition is that total revenue, valued at the output price net of production taxes, PC_{id} , multiplied by Q_{id} equals the total production cost.

$$PC_{id} \cdot Q_{id} = \sum_c P_{id}^c \cdot X1_{id}^c + \sum_o W_{id}^o \cdot L_{id}^o + R_{id} \cdot K_{id} + RLND_{id} \cdot LND_{id} \quad (16)$$

Table 6. Definitions of variables and parameters in composite factor demands

| Variables | |
|------------------------------|---|
| xtot(i,d) | Industry outputs |
| atot(i,d) | All-input-augmenting technical change |
| aint_s(c,i,d) | Intermediate tech change |
| delPTX(i,d) | Ordinary change in production tax revenue |
| pcst(i,d) | Ex-tax cost of production |
| ptot(i,d) | Industry output prices |
| delPTXRATE(i,d) | Change in rate of production tax |
| Values and parameters | |
| SRCSHR(c,s,u,d) | Imp/ dom shares |
| VCST(i,d) | Total cost of industry i |
| PRODTAX(i,d) | Taxes on production |

Source: Authors' construction.

Next, we introduce production taxes to industry costs. Production tax revenue, $VPTX_{id}$, is calculated as the tax rate $RPTX_{id}$ multiplied by the value of output. The industry output price $PTOT_{id}$ is inclusive of production taxes.

$$VPTX_{id} = RPTX_{id} \cdot PC_{id} \cdot Q_{id} \quad (17)$$

$$PTOT_{id} \cdot Q_{id} = PC_{id} \cdot [1 + RPTX_{id}] \cdot Q_{id} \quad (18)$$

Listing 4. Composite factor demands (partial GEMPACK coding)

$$xprim(i,d) = xtot(i,d) + atot(i,d) + aprim(i,d); \quad (T13)$$

$$xint_s(c,i,d) = atot(i,d) + aint_s(c,i,d) + xtot(i,d) - 0.15 * \{ppur_s(c,i,d) + aint_s(c,i,d) - pint(i,d)\}; \quad (T14)$$

$$ppur_s(c,u,d) = \text{sum}\{s, SRC, SRCSHR(c,s,u,d) * ppur(c,s,u,d)\}; \quad (T15)$$

$$VCST(i,d) * [pcst(i,d) - atot(i,d)] = PRIM(i,d) * [aprim(i,d) + pprim(i,d)] + PUR_CS(i,d) * pint(i,d); \quad (T16)$$

$$\text{delPTX}(i,d) = 0.01 * \text{PRODTAX}(i,d) * [xtot(i,d) + pcst(i,d)] + VCST(i,d) * \text{delPTXRATE}(i,d); \quad (T17)$$

$$VTOT(i,d) * [ptot(i,d) + xtot(i,d)] = VCST(i,d) * [pcst(i,d) + xtot(i,d)] + 100 * \text{delPTX}(i,d); \quad (T18)$$

In applications of the model in which industries have multi-product capability, supplies of commodity c by industry i in region d (MQ_{cid}) follow a CET relationship between industry output prices and the average commodity price $PDOM_{cd}$, which is the basic domestic price (see (50)).

$$MQ_{cid} = f(Q_{id}, CET(PDOM_{cd} / PTOT_{id})) \quad (19)$$

$$PTOT_{id} Q_{id} = \sum_c PDOM_{cd} \cdot MQ_{cid} \quad (20)$$

We assume that the supply of imports is infinitely elastic. Hence, the price of imports, PM_{cd} , is determined by foreign import prices, PFM_{cd} and the nominal exchange rate ϕ .

$$PM_{cd} = PFM_{cd} \cdot \phi \quad (21)$$

Table 7. Definitions of variables and parameters in industry supplies

| Variables | |
|-----------------------|--|
| xmake(c,i,d) | Output of commodity c by industry i in d |
| pmake(c,i,d) | Price received by industries |
| pdom(c,r) | Output prices = basic prices of domestic commodities |
| xcom(c,d) | Total output of commodities |
| Values and parameters | |
| phi | Exchange rate, local currency/\$world |
| pimp(c,r) | Import prices, local currency |
| pfimp(c,r) | Import prices, foreign currency |
| SIGMAOUT(i) | Constant elasticity of transformation parameter (positive) |

Source: Authors' construction..

The TABLO coding for multi-product industries is:

Listing 5. Industry supplies (partial GEMPACK coding)

```
xmake(c,i,d)=xtot(i,d)+SIGMAOUT(i)*[pmake(c,i,d)-ptot(i,d)]; (T19)
pmake(c,i,d)=pdom(c,d)-0.05*[xmake(c,i,d)-xcom(c,d)]; (T20)
pimp(c,r) = pfimp(c,r) + phi; (T21)
```

Equation T20 above provides that where a commodity is produced by two different industries, the two sources are regarded as very good substitutes (CES=20).

3.3 Household demands

The linear expenditure system (LES) is based on a utility function (U) which splits household spending on each commodity ($XHOU_c$) into two, a subsistence component $XSUB_c$ that depends only on the number of households (N) and preferences, and a luxury component, $XLUX_c$, which depends on prices and income in a Cobb-Douglas form. β_c is the marginal budget (i.e., aggregate spending minus aggregate subsistence spending) share of commodity c. Regional and household dimensions are omitted from equations (22) to (33).

$$U = \frac{1}{N} \prod_c (XHOU_c - XSUB_c)^{\beta_c} \quad (22)$$

Aggregate spending ($WHOU$) is of the form:

$$WHOU = \sum_c P3_c XHOU_c = \sum_c P3_c XSUB_c + [WHOU - \sum_c P3_c XSUB_c] \quad (23)$$

From this, we obtain the linear expenditure function, where P3c is the price faced by household consumers of commodity c:

$$P3_c XHOU_c = P3_c XSUB_c + \beta_c [WHOU - \sum_d P3_d XSUB_d] \quad (24)$$

Aggregate subsistence expenditure $\sum_c WSUB_c$ is given by:

$$\sum_c WSUB_c = \sum_c P3_c XSUB_c \quad (25)$$

The Frisch “parameter” is the (negative) ratio of total expenditure to luxury expenditure:

$$Frisch = -WHOU / [WHOU - \sum_c WSUB_c] \quad (26)$$

The ORANI school (Dixon et al., 1982) typically assigns a Frisch “parameter” of -1.82 to a model for a relatively high income nation (footnote 2 at the end of this section refers to modeling dealing with rapid consumption growth over time).

Differentiating equation (24) with respect to $WHOU_c$, and multiplying by $WHOU_c / [XHOU_c P3_c]$, we calculate the expenditure elasticity EPS_c . This is equal to the marginal budget share divided by the budget share ($SHOU_c = P3_c XHOU_c / WHOU_c$) for each commodity:

$$EPS_c = \beta_c WHOU_c / [P3_c XHOU_c] \quad (27)$$

$BLUX_c$ is the ratio of luxury expenditure to total expenditure on each commodity, given by:

$$BLUX_c = \beta_c [WHOU - \sum_d WSUB_d] / [P3_c XHOU_c] \quad (28)$$

Substituting equations (26) and (27) into equation (28):

$$BLUX_c = -EPS_c / Frisch \quad (29)$$

Next, we calculate the matrix of price elasticities implied by LES. By differentiating equation (24) with respect to $P3_d$ [i.e., $dXHOU_c / dP3_d = -\beta_c XSUB_d / P3_c$], we calculate the off-diagonal elements of the price elasticity matrix (η_{cd}):

$$dXHOU_c / dP3_d \cdot [P3_d / XHOU_c] = -\beta_c (WHOU) (P3_d XSUB_d) / (WHOU \cdot P3_c) \cdot [P3_d / XHOU_c] \quad (30)$$

$$\eta_{cd} = \beta_c (1 - BLUX_d) \cdot SHOU_d / SHOU_c \quad (31)$$

We obtain the diagonal elements by dividing equation (24) by $P3_c$ and differentiating with respect to $P3_c$:

$$dXHOU_c / dP3_c \cdot [P3_c / XHOU_c] = -\beta_c WHOU_c / [P3_c XHOU_c] + \sum_d \beta_c (WHOU) P3_d XSUB_d / [(WHOU \cdot P3_c) \cdot [P3_c XHOU_c]] \quad (32)$$

Substituting equations (27) and (31) into equation (32), we obtain:

$$\eta_{cc} = -EPS_c - \sum_{d \neq c} \eta_{cd} \quad (33)$$

LES does not allow for specific substitutability. Where appropriate, specific substitutes could form a CES nest, with the CES composite commodity entering LES within the model. In addition, LES does not allow for commodities with negative income elasticities.

SinoTERM365 includes provision for multiple households in each bottom-up region. At present, there is only one household in the database in each region. Individual households are denoted by *h*.

Table 8. Definitions of variables and shares in the household demand system

| Variables | |
|--------------------------|---|
| xhouh_s(c,d,h) | Household demands |
| wlux(d,h) | Total nominal supernumerary household expenditure |
| xhouhtot(d,h) | Total real household consumption |
| whouhtot(d,h) | Total nominal household consumption |
| phouhtot(d,h) | CPI |
| nhouh(d,h) | Number of households |
| xlux(c,d,h) | Household - supernumerary demands |
| xsub(c,d,h) | Household - subsistence demands |
| alux(c,d,h) | Taste change, supernumerary demands |
| asub(c,d,h) | Taste change, subsistence demands |
| ahou_s(c,d,h) | Taste change,household imp/dom compsite |
| Values and shares | |
| BLUX(c,d,h) | Luxury share of expenditure on commodity <i>c</i> |
| BUDGSHR(c,d,h) | Budget share |
| SLUX(c,d,h) | Marginal budget share |

Source: Authors' construction.

Rather than include the general household demand equation in the model with the elasticities implied by equations (31) and (33), the LES in SinoTERM365 is coded as shown in Listing 5.

Listing 6. Household demand system (partial GEMPACK coding)

```

xlux(c,d,h) + phou(c,d) = wlux(d,h) + alux(c,d,h); (T24a)
xhouh_s(c,d,h) = BLUX(c,d,h)*xlux(c,d,h) + [1-BLUX(c,d,h)]*xsub(c,d,h); (T24b)
alux(c,d,h) = asub(c,d,h) - sum{k,COM, SLUX(k,d,h)*asub(k,d,h)}; (T24d)
asub(c,d,h) = ahou_s(c,d,h) - sum{k,COM, BUDGSHR(k,d,h)*ahou_s(k,d,h)}; (T24e)
xsub(c,d,h) = nhouh(d,h) + asub(c,d,h); (T25)
xhouhtot(d,h) = sum{c,COM,BUDGSHR(c,d,h)*xhouh_s(c,d,h)};
phouhtot(d,h) = sum{c,COM,BUDGSHR(c,d,h)*phou(c,d)};
whouhtot(d,h) = phouhtot(d,h) + xhouhtot(d,h);

```

A formula within the TABLO code calculates the share term $BLUX_c$ from equation (29) and $SLUX_c$ based on equation (25). The Frisch “parameter” and expenditure elasticities are updated as the subsistence share of consumption changes. The usual practice has been to assign $XSUB_c$ as fixed. In modeling relatively local changes, this is not an issue. But in dynamic modeling, particularly when dealing with rapid income growth as in the case of the Chinese economy, growing aggregate consumption results in $XSUB_c$ shrinking as a share of total consumption of each commodity. This implies that the LES system will tend towards Cobb-Douglas. If this is unsatisfactory in a particular scenario, the modeler may choose to increase per capita subsistence consumption over time. This is justifiable on the basis that yesterday’s luxuries are today’s necessities. An alternative functional form to LES that copes better with growth in consumption over time is the AIDADS form, which also allows inferior commodities (Rimmer and Powell 1996).

To accommodate changes in per capita subsistence quantities, we may add to SinoTERM365 an equation defining the percentage change in the Frisch “parameter”, $wfrisch$:

$$wfrisch(d,h) = whoutot(d,h) - wlux(d,h); \quad (T26)$$

A subsistence taste shifter $asub_c$ is added to the following:

$$xsub(c,d,h) = nhou(d,h) + asub(c,d,h) + asub_c(d,h); \quad (T24f)$$

$$\begin{aligned} alux(c,d,h) &= asub(c,d,h) - asub_c(d,h) \\ -sum\{k, COM, SLUX(k,d) * [asub(k,d,h) - asub_c(d,h)]\}; \end{aligned} \quad (T24g)$$

In order to target a given shift in subsistence expenditures, the variable $wfrisch$ is made exogenous by swapping with $asub_c$.²

3.4 Investment demands

Following ORANI, the commodity composition of investment varies between industries. The amount of commodity c demanded by investment industry i in region d , $X2_{id}^c$, is proportional to the industry investment quantity, $X2TOT_{id}$, for a given investment technology $A2_{id}^c$. $P2_{cd}$ is the commodity-specific investment price.

$$X2_{id}^c = A2_{id}^c \cdot X2TOT_{id} \quad (34)$$

$$P2_{cd} \cdot X2_{cd} = P1_{Inv,d}^c \cdot X1_{Inv,d}^c \quad \text{Inv} \in \text{User} \quad (35)$$

² In a dynamic simulation of an earlier SinoTERM version developed by the authors, aggregate consumption per capita grew by more than 785 percent between 2006 and 2030. In the forecast baseline, shocks to $wfrisch$ were set equal to minus 15 percent of the growth in aggregate consumption. Starting with an absolute Frisch ratio of 2.5 in 2007, the ratio had moved in each region of the model to around 1.75 by 2030 (see <http://www.copsmodels.com/archivep.htm> item TPGW0169).

$$PI2_{id} \cdot X2TOT_{id} = \sum_c X2_{id}^c \cdot P1_{Inv,d}^c \quad \text{Inv} \in \text{User} \quad (36)$$

$$GR_{id} = R_{id} / PI2_{id} \quad (37)$$

Equation (34) calculates an industry investment price index. Equation (35) defines the gross rate of return (GR_{id}) as the ratio of the capital rental to the price of new capital (i.e., the industry investment price index).

$$IKRAT_{id} = X2TOT_{id} / K_{id} \quad (38)$$

$$IKRAT_{id} = f[(GR_{id})^2 / \text{Islack}]^{0.33} \quad (39)$$

Equation (36) defines the investment-to-capital ratio ($IKRAT_{id}$). Typically the gross rate of return is exogenous in long-run simulations, with capital stocks (K_{id}) endogenous - and the converse in the short run. *Islack* is exogenous except when the simulation is accommodating a macro investment target. Equation (37) causes investment to grow when the rate of return increases (the 2 and 0.33 exponents are those used in the ORANI short-run investment rule). Dynamic applications of TERM have in addition a dynamic accumulation equation linking present capital, past capital net of depreciation and past investment (see Dixon and Rimmer, 2002, section 21).

Table 9: Definitions of variables and shares in investment demands

| Variables | |
|------------------|---|
| xinviot(i,d) | Investment by industry |
| pinviot(i,d) | Investment price index by industry |
| gret(i,d) | Gross rate of return = Rental/[Price of new capital] |
| ggro(i,d) | Gross growth rate of capital = Investment/capital |
| finv1(i,d) | Investment shift variable |
| invslack | Investment slack variable for exogenizing national investment |
| fgret(i,d) | Shifter to lock together industry rates of return |
| capslack | Slack variable to allow fixing aggregate capital |
| Values | |
| INVEST_I(c,d) | Investment by commodity and region |
| INVEST_C(i,d) | Investment by industry and region |

Source: Authors' calculation.

Listing 7. Investment demands (partial GEMPACK coding)

```

xinvi(c,i,d) = xinviot(i,d);                                (T26)
INVEST_I(c,d)*xinv_s(c,d) = sum{i,IND,INVEST(c,i,d)*xinvi(c,i,d)};    T25)
INVEST_C(i,d)*pinviot(i,d) = sum{c,COM,INVEST(c,i,d)*pinvest(c,d)};    (T26)
gret(i,d) = pcap(i,d) - pinviot(i,d);                        (T27a)
gret(i,d) = fgret(i,d) + capslack;                          (T27b)
ggro(i,d) = xinviot(i,d) - xcap(i,d);                       (T31)
ggro(i,d) = finv1(i,d) + 0.33*[2.0*gret(i,d) - invslack];    (T32)

```

3.5 Other final demands

Government demands XG_{cd} are independent of prices and proportional to three corresponding shifters. They shift the demand function with different dimensions: by d as FG_c , by c and d, as FGS_{cd} and by c, s, and d, as $FGOV_{csd}$.

$$XG_{cd} = FG_c . FGS_{cd} . FGOV_{csd} \quad (40)$$

Export demands follow a two-stage process. First, regional source-specific exports $X4_{cd}$ form a CES composite $X4NAT_c$, with the CES parameter for inter-regional substitutability set to 5:

$$X4_{cd} = f(X4NAT_c, CES[P4_{cd} / P4NAT_c]) \quad (41)$$

$$P4_{cd} = P1_{Exp,d}^c \quad \text{Exp} \in \text{User} \quad (42)$$

$$P4NAT_c . X4NAT_c = \sum_d X4_{cd} . P4_{cd} \quad (43)$$

Next, national exports are linked to international demands. $FP4NAT_c$ and $FQ4_c$ are demand shifters, and γ the export demand elasticity.

$$X4NAT_c = (P4NAT_c / FP4NAT_c)^{-\gamma} FQ4_c \quad (44)$$

Inventories XST_{id} are proportional to $XTOT_{id}$ multiplied by a shifter, FST_{id} .

$$XST_{id} = Q_{id} . FST_{id} \quad (45)$$

Table 10: Definitions of variables and parameters in other final demands

| Variables | |
|-----------------------|---|
| ppur_exp(c) | Export price P4NAT |
| xpur_exp(c) | National export volume X4NAT |
| natfqexp(c) | Export quantity shift variable |
| natfpexp(c) | Export price shift variable |
| natfpexp_c | Macro shifter |
| xexp(c,s,d) | Export of all-region composite leaving port |
| xgov(c,s,d) | Government demands |
| fgov(c,s,d) | Government demand shifter |
| fgov_s(c,d) | Government demand shifter |
| fgovtot(d) | Government demand shifter |
| xgov_s(c,d) | Government demands, dom+imp |
| xstocks(i,d) | Inventories |
| Values and parameters | |
| TRADE_D(c,s,r) | TRADE matrix summed across destinations |
| TRADE_R(c,s,d) | TRADE matrix summed across origins |
| TRADE_RD(c,s) | TRADE matrix summed across origins and |
| EXP_ELAST(c) | Export demand elasticity |
| PUR(c,s,u,d) | Purchasers' prices |

Source: Authors' construction.

Listing 8. Other final demands (partial GEMPACK coding)

$$xgov(c, s, d) = fgovtot(d) + fgov(c, s, d) + fgov_s(c, d); \quad (T40a)$$

$$xgov_s(c, d) = \text{sum}\{s, SRC, SRCshr(c, s, "Gov", d) * xgov(c, s, d)\}; \quad (T40b)$$

$$xexp(c, "dom", d) = xpur_exp(c) - 5 * [ppur(c, "dom", "Exp", d) - ppur_exp(c)]; \quad (T41)$$

$$ppur_exp(c) = \text{sum}\{d, Dst, PUR(c, "dom", "exp", d) * ppur(c, "dom", "Exp", d)\}; \quad (T43)$$

$$xpur_exp(c) - natfqexp(c) = -EXP_ELAST(c) * [ppur_exp(c) - phi - natfpexp(c) - natfpexp_c]; \quad (T44)$$

$$xstocks(i, d) = xtot(i, d); \quad (T45)$$

3.6 Margins

TERM separates the market for margins from the market for commodities being delivered by margins m (Dixon et al., 1982). Demands for margins XTM_{rd}^{csm} are proportional to commodity demands XT_{rd}^{cs} subject to a margins-using technology ATM_{rd}^{csm} (equation (46)).

$$XTM_{rd}^{csm} = ATM_{rd}^{csm} \cdot XT_{rd}^{cs} \quad (46)$$

In equation (47), $PBAS_r^{cs}$ is the basic commodity price and PM_{rd}^m the margins' prices. PU_d^{cs} is the margins-inclusive, tax-exclusive source-composite delivered price that appears in equation (3.4).

$$PD_{rd}^{cs} \cdot XT_{rd}^{cs} = PBAS_r^{cs} \cdot XT_{rd}^{cs} + \sum_m PM_{rd}^m \cdot XTM_{rd}^{csm} \quad (47)$$

$$PMR_{rd}^m \cdot XMR_{rd}^m = \sum_p XMP_{rd}^{pm} \cdot PDOM_r^m \quad (48)$$

$$XMP_{rd}^{pm} = f(XMR_{rd}^m, CES[PDOM_r^m / PMR_{rd}^m]) \quad (49)$$

$$PBAS_d^{c, dom} = PDOM_{cd} \quad (50)$$

$$PBAS_d^{c, imp} = PIMP_{cd} \quad (51)$$

A third context is introduced for sub-national regions in equation (46). In addition to regional origins r and destinations d for commodity and services, regions p also produce margins. A shipping company that moves commodities from origin in Chongqing to a destination in Shanghai may be based in Wuhan (i.e., the margins producing region). The Wuhan company competes with shipping companies from other regions through CES substitution between regional providers p of margins in equation (49). PMR_{rd}^m is the price of margins summed across providers p . XMP_{rd}^{mp} is the level of margins provided by p to move commodities from region r to d and XMR_{rd}^m the provider composite.

Table 11 contains the definition of variables, values and shares concerning margins, followed by the TABLO coding.

Table 11. Definitions of variables, shares and parameters in margins

| Variables | |
|--------------------------------------|--|
| xtradmar(c,s,m,r,d) | Margin m on commodity c,s going from r to d |
| atradmar(c,s,m,r,d) | Tech change: margin m on commodity c,s going from r to d |
| atradmar_cs(m,r,d) | Tech change: margin m on commodities going from r to d |
| asuppmar(m,r,d,p) | Tech change, Margin m supplied by p on commodities passing from r to d |
| xsuppmar(m,r,d,p) | Demand for margin m (made in p) on commodities from r to d |
| xsuppmar_d(m,r,p) | Total margins on commodities from r, produced in p |
| pdelivrd(c,s,r,d) | All-user delivered price of commodity c,s from r to d |
| psuppmar_p(m,r,d) | Price of composite margin m on commodities from r to d |
| xsuppmar_p(m,r,d) | Quantity of composite margin m on commodities from r to d |
| xsuppmar_rd(m,p) | Total demand for margins produced in p |
| pbasic(c,s,r) | Basic prices |
| Values, shares and parameters | |
| BASSHR(c,s,r,d) | Share of basic value in all-user delivered price |
| MARSHR(c,s,m,r,d) | Share of margin m in all-user delivered price |
| DELIVRD_R(c,s,d) | Demand in region d for delivered commodities from all |
| SUPPMAR_P(m,r,d) | Total demand for margin m on commodities from r to d |
| SUPPMAR_D(m,r,p) | Total demand for margin m (from p) on commodities from r |
| SUPPMAR(m,r,d,p) | Margins supplied by p on commodities passing from r to d |
| SIGMAMAR(m) | Substitution elasticity between margin origins |

Source: Authors' construction.

Listing 9. Margins (partial GEMPACK coding)

```

xtradmar(c,s,m,r,d)=xtrad(c,s,r,d)+atradmar(c,s,m,r,d); (T46)

pdelivrd(c,s,r,d) = BASSHR(c,s,r,d)*pbasic(c,s,r) +
sum{m,MAR,MARSHR(c,s,m,r,d)*[psuppmar_p(m,r,d)+atradmar(c,s,m,r,d)]}; (T47)

SUPPMAR_P(m,r,d)*psuppmar_p(m,r,d) =
sum{p,PRD,SUPPMAR(m,r,d,p)*[pdom(m,p)+asuppmar(m,r,d,p)]}; (T48)

xsuppmar(m,r,d,p) = xsuppmar_p(m,r,d) + asuppmar(m,r,d,p)
-SIGMAMAR(m)*[pdom(m,p)+asuppmar(m,r,d,p)-psuppmar_p(m,r,d)]; (T49)

pbasic(c,"dom",r) = pdom(c,r); (T50)

pbasic(c,"imp",r) = pimp(c,r); (T51)

```

3.7 Market clearing equations and macro equations

Equation (52) is the market clearing condition for industry outputs. Additional market clearing equations are required due to the common sourcing assumption. Equation (53) links non-margins (a subset of commodities, denoted by nm) commodity sales summed across destinations to regional supplies and equation (54) does so for the margins subset (m). Equation (55) links sales summed across users to supplies summed across regional origins.

$$PTOT_{id} \cdot Q_{id} + XST_{id} = \sum_c MQ_{cid} \quad (52)$$

$$\sum_d PDOM_{rd}^{nm} \cdot XT_{rd}^{nm,dom} = \sum_i MQ_{nm,ir} \quad (53)$$

$$\sum_i MQ_{mip} = \sum_d PDOM_{pd}^m \cdot XT_{pd}^{m,dom} + \sum_r \sum_d XMP_{rd}^{pm} \quad (54)$$

$$\sum_u X_{ud}^{cs} \cdot P_{ud}^{cs} = PU_{sd}^c \cdot XT1_d^{cs} \quad (55)$$

$$XMR_{rd}^m = \sum_c \sum_s XTM_{rd}^{csm} \quad (56)$$

Next, we calculate GDP on the expenditure ($GDPE_d$) and income sides ($GDPE_i$). GDP on each side is set equal by the above market clearing equations.

$$\begin{aligned} GDPE_d = & \sum_u PI_{ud}^c \cdot X1_{ud}^c + \sum_i PTOT_{id} \cdot XST_{id} - \sum_c \sum_r PT_{dr}^{c,imp} \cdot XT_{dr}^{c,imp} \\ & + \sum_m (\sum_{dst} PMR_{dst,d}^m \cdot XMR_{dst,d}^m - \sum_p PMR_{dp}^m \cdot XMR_{dp}^m) + \sum_c \sum_s (\sum_{dst} PT_{d,dst}^{cs} \cdot XT_{d,dst}^{cs} - PT_{dd}^{cs} \cdot XT_{dd}^{cs}) \\ & - \sum_c \sum_s (\sum_{org} PT_{org,d}^{cs} \cdot XT_{org,d}^{cs} - PT_{dd}^{cs} \cdot XT_{dd}^{cs}) \end{aligned} \quad (57)$$

$$GDPI_d = \sum_i PF_{id} \cdot F_{id} + \sum_i VPTX_{id} + \sum_u \sum_c \sum_s PU_{sd}^c \cdot XT1_d^{cs} \cdot (T_{ud}^{cs} - 1) \quad (58)$$

Equation (59) is the consumption function where APC_d is the average propensity to consume based on labor income $LTOT_d (= \sum_i \sum_o W_{id}^o \cdot L_{id}^o)$ and a consumption function shifter ($FHOU_d$).

$$WHOU_d = LTOT_d \cdot APC_d \cdot FHOU_d \quad (59)$$

Table 12: Definitions of variables, values and mappings in market clearing and macro equations

| Variables | |
|----------------------------|--|
| xtrad_d(c,s,r) | Total direct demands for commodities produced(dom) or landed(imp) in r |
| delXGDPEXP(d,i) | Ordinary change in quantity expenditure G |
| xgdpexp(d) | Real expenditure GDP |
| xfin(u,d) | Final user quantity indices |
| wlnd_i(d) | Total rentals to land |
| wcap_i(d) | Total rentals to capital |
| wlab_io(d) | Total wage bill |
| delTAXint(c,s,i,d) | Ordinary change in intermediate input taxes |
| delTAXhou(c,s,d) | Ordinary change in household commodity taxes |
| delTAXinv(c,s,d) | Ordinary change in investment commodity taxes |
| delTAXgov(c,s,d) | Ordinary change in government commodity taxes |
| delTAXexp(c,s,d) | Ordinary change in export commodity taxes |
| delGDPINC(d,i) | Ordinary change in nominal income GDP composition |
| wgdpinc(d) | Nominal income GDP |
| houslack | Consumption slack variable to accommodate national constraint |
| fhou(h,d) | Regional propensity to consume from labor income |
| Values and mappings | |
| MAKESHR2(c,i,d) | Industry share in commodity supply |
| MAKE_I(c,d) | Total production of commodities |
| SUPPMAR_RD(m,p) | Total demand for margin m produced in p |
| USE(c,s,u,d) | Delivered value of demands: basic + margins |
| USE_U(c,s,d) | Total delivered value of regional composite |
| USE_I(c,s,d) | All-intermediate delivered value of regional composite |
| TRADMAR(c,s,m,r,d) | Margins on trade matrix |
| TRADMAR_CS(m,r,d) | Total demand for margin m on commodities fro |
| SCOM2IND | Mapping from SCOM commodity to industry |
| STOCKS(i,d) | Domestic inventories |
| LAB_IO(d) | Total wages |
| LND_I(d) | Total rentals to land |
| CAP_I(d) | Total rentals to capital |
| GDPINC SUM(d,i) | Income GDP breakdown |
| GDPINC(d) | Income GDP |

Source: Authors' construction.

In the TABLO coding, the commodities set is divided into two in (52). MCOM (denoted by mc) refers to commodities produced by several industries, and SCOM (sc) to commodities produced by a single industry. The set MCOMIND refers to industries producing commodities within the MCOM subset. There are computational efficiency gains from not assuming that all industries are potentially multi-product. Expenditure-side GDP in region q is computed by adding up elements of the set GDPEXPCAT. The set FINDEM (f), a subset of USR, refers to final demands. The add-up of income-side GDP follows. The set GDPINCCAT includes all factors, commodity taxes and production taxes.

Listing 10. Market clearing and macro equations (partial GEMPACK coding)

```

xcom(mc,d)=sum{i,MCOMIND,MAKESHR2(mc,i,d)*xmake(mc,i,d)}; (T52a)
xcom(sc,d)=xmake(sc,SCOM2IND(sc),d); (T52b)
xcom(nm,r) = xtrad_d(nm,"dom",r); (T53)
MAKE_I(m,p)*xcom(m,p) = TRADE_D(m,"dom",p)*xtrad_d(m,"dom",p)
+ SUPPMAR_RD(m,p)*xsuppmar_rd(m,p); (T54)
USE_U(c,s,d)]*xtrad_r(c,s,d) = USE_I(c,s,d)*xint_i(c,s,d)
+ USE(c,s,"hou",d)*xhou(c,s,d) + USE(c,s,"inv",d)*xinv(c,s,d)
+USE(c,s,"gov",d)*xgov(c,s,d)+USE(c,s,"exp",d)*xexp(c,s,d); (T55)
TRADMAR_CS(m,r,d)*xsuppmar_p(m,r,d) =
sum{c,COM,sum{s,SRC,TRADMAR(c,s,m,r,d)*xtradmar(c,s,m,r,d)}}; (T56)
delXGDPEXP(q,f) =0.01*PUR_CS(f,q)*xfin(f,q); (T57a)
delXGDPEXP(d,"Stocks")=
0.01*sum{i,IND,STOCKS(i,d)*xstocks(i,d)}; (T57b)
delXGDPEXP(q,"Imports") = -
0.01*sum{c,COM,TRADE_D(c,"imp",q)*xtrad_d(c,"imp",q)}; (T57c)
delXGDPEXP(q,"NetMar") = 0.01*sum{m,MAR,sum{r,ORG,sum{d,DST,
SUPPMAR(m,r,d,q)*xsuppmar(m,r,d,q)} -sum{p,PRD,
SUPPMAR(m,r,q,p)*xsuppmar(m,r,q,p)}}}; (T57d)
delXGDPEXP(q,"Rexports") = 0.01*sum{c,COM,sum{s,SRC,
TRADE_D(c,s,q)*xtrad_d(c,s,q) - TRADE(c,s,q,q)*xtrad(c,s,q,q)}}; (T57e)
delXGDPEXP(q,"Rimports") =-0.01*sum{c,COM,sum{s,SRC,
TRADE_R(c,s,q)*xtrad_r(c,s,q)-TRADE(c,s,q,q)*xtrad(c,s,q,q)}}; (T57f)
GDPEXP(q)*xgdpepx(q)=100*sum{i,GDPEXPCAT, delXGDPEXP(q,i)}; (T57g)
delGDPINC(d,"Land") =0.01*LND_I(d)*wlnd_i(d); (T58a)
delGDPINC(d,"Capital") =0.01*CAP_I(d)*wcap_i(d); (T58b)
delGDPINC(d,"Labor") =0.01*LAB_IO(d)*wlab_io(d); (T58c)
delGDPINC(d,"ProdTax") =sum{i,IND,delPTX(i,d)}; (T58d)
delGDPINC(d,"ComTax") =sum{c,COM,sum{s,SRC,
sum{i,IND,delTAXint(c,s,i,d)}+delTAXhou(c,s,d)
+delTAXinv(c,s,d)+delTAXgov(c,s,d)+delTAXexp(c,s,d)}}; (T58e)
GDPINC(d)*wgdpinc(d) =100*sum{i,GDPINCCAT,delGDPINC(d,i)}; (T58f)
whouhtot(d,h) = wlab_io(d) + fhou(d,h) + houslack; (T59)

```

4. Simulation: Reducing China's Use of Coal

4.1 The scenario

This illustrative simulation with an aggregation of SinoTERM365 is based on global expectations that coal-fired electricity generation will fall in China and elsewhere in the long run in order to reduce greenhouse gas emissions.

The two shocks imposed on each region in the aggregation are:

1. A 50% increase in hydroelectricity output and capital.
2. A 20% decrease in inputs of coal-generated electricity per unit of output and a 50% increase in hydroelectric inputs per unit of output in all industries.³

We explain the change in real GDP for the biggest loser, RoShanxi (Shanxi excluding the prefecture of Shuozhou). Coal's share of GDP in RoShanxi is 12.2%, and the respective shares for coal- and hydro-generated electricity are 5.3% and 0.4% (Table 13, columns 1 to 3). The coal output loss of 1% (Table 13, column 4) is equivalent to a real GDP loss of 0.12% ($=12.2\% \times -0.01$), the coal-generation output loss of 16.4% is equivalent to a real GDP loss of 0.9% ($=5.3\% \times -0.164$) and the hydro-generated gain is equivalent to a real GDP gain of 0.2% ($=0.4\% \times 0.5$). These contributions sum to a real GDP change of -0.82%, bigger than the modeled real GDP change of -0.6% (Table 13, column 6).

Since real wages in RoShanxi fall by 0.3%, employment losses end up being less than 0.82% at 0.7%. That is, a weakened labor market adjusts partly through falling real wages and partly through labor migration to other regions. Some industries, notably services that are heavily reliant on local household demands (aggregate consumption falls by 1.0%), suffer output decreases due to the decline in local demand. Other sectors including farming, non-coal mining activity and manufactures increase output due to improved competitiveness arising from lower real wages.

RoShanxi is a net exporter of coal and coal-generated electricity to other regions, so that a decline in national demand for coal-generated electricity has a negative impact on RoShanxi's terms-of-trade (-0.2%). This reduction in spending power implies that real consumption (-1.0%) falls by a larger percentage than real GDP (-0.6%).

³ Equation (14) of the core model allows only weak endogenous substitutability between different forms of electricity. Adams and Parmenter (2013) include an additional CES nest to depict strong substitutability between generators, and Peters (2016) introduces electricity substitutability into the GTAP-E model: such modifications makes the exogenous demand switch modelled here unnecessary. The files to reproduce this simulation accompany the article.

Table 13. Long-run effects of 50% increase in hydropower supply, and demand switch from coal-generated electricity to hydropower

| | Coal share of GDP % | Coal-generated electricity as % of GDP | Hydro-generated electricity as % of GDP | Coal output | Coal-gen. electricity output | Real GDP | Regional terms of trade | Aggregate consumption | Employment | Real wage | Aggregate capital |
|-----------|---------------------|--|---|-------------------------|------------------------------|----------|-------------------------|-----------------------|------------|-----------|-------------------|
| | Base year data | | | % change from base case | | | | | | | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) |
| ErdosIM | 62.2 | 1.9 | 0.2 | -0.6 | -16.9 | -0.1 | -0.2 | -0.7 | -0.5 | -0.1 | -1.0 |
| RoIM | 7.8 | 3.5 | 0.3 | -1.2 | -16.8 | -0.1 | -0.1 | -0.4 | -0.4 | 0.0 | -0.9 |
| ShuozhouS | 36.3 | 1.1 | 1.6 | -0.7 | -17.0 | 0.7 | -0.6 | 0.0 | -0.2 | 0.2 | 0.7 |
| RoShanxi | 12.2 | 5.3 | 0.4 | -1.0 | -16.4 | -0.6 | -0.2 | -1.0 | -0.7 | -0.3 | -1.2 |
| Shaanxi | 10.8 | 0.6 | 0.0 | -1.0 | -17.1 | 0.1 | 0.3 | 0.2 | -0.1 | 0.3 | -0.3 |
| HuaiBeiAH | 24.3 | 3.8 | 0.0 | -1.0 | -16.8 | -0.4 | 0.2 | -0.3 | -0.4 | 0.0 | -1.1 |
| RoAnhui | 2.3 | 2.1 | 0.2 | -1.6 | -16.9 | 0.1 | 0.1 | 0.1 | -0.1 | 0.3 | -0.5 |
| RoChina | 0.8 | 1.0 | 0.5 | -0.9 | -17.2 | 0.3 | 0.1 | 0.5 | 0.0 | 0.4 | 0.1 |
| National | 1.9 | 1.2 | 0.5 | -0.9 | -17.1 | 0.3 | 0.0 | 0.4 | 0.0 | 0.4 | 0.0 |

Source: Authors' calculation

On the income side, real GDP is a function of primary factor inputs, indirect tax income and technology. Since aggregate primary factors are unchanged at the national level in the scenario (Table 13, bottom row), the modeled change in real GDP (0.3% nationally) is due to technological change. The targeted output increase of 50% for hydro-generated electricity in all regions was achieved by making primary factor productivity for sector endogenous. Net input savings also arose in the switch from coal- to hydro-generated electricity. A cost-neutral switch would have resulted in a lower real GDP gain.⁴

Overall, even this stylized simulation shows that relatively coal-intensive regions are vulnerable to downturns if China's energy mix switches away from coal towards renewables. As coal mines close, losses in regions such as the Erdos prefecture in Inner Mongolia (ErdosIM) may be more substantial than are modeled in this scenario.

5. Conclusion

This paper has outlined the TERM methodology, the objective of which is to depict more sectoral and regional disaggregation than other multi-regional, sub-

⁴ Users of the online files for running the simulation will see the decomposition of national real GDP into changes in factors, technology and taxes in the variable contincagg_d. This explanatory variable is excluded from the code shown in section 3.

national AGE models. The major contribution is to apply the approach to China, for which data are quite scarce. Other models of China, including earlier versions of SinoTERM, confine regional detail to the provincial level. SinoTERM365 is the first AGE model of China with prefectural detail in 365 regions. We make the most of scarce data using assumptions such as identical industry technologies in different regions and the gravity assumption to estimate inter-regional trades. In examples in which the assumption of identical technologies is suspect, such as in electricity generation, we disaggregate the sectoral dimension further so as to make the assumption defensible.

Table 14. TERM and SinoTERM online resourcesa

| Description | Reference |
|--|------------------|
| TERM database generation programs | tpmh0067 |
| Files to replicate SinoTERM simulation reported in Horridge and Wittwer (2008) | tpgw0079 |
| Files to replicate SinoTERM simulation reported in Wittwer and Horridge (2009) | tpgw0086 |
| Files to replicate Australian TERM simulation reported in Wittwer and Horridge (2010) | tpmh0116 |
| Example of Polish TERM | tpmh0117 |
| Example of Indonesian TERM | tpmh0118 |
| Files required for simulations in South African version of TERM teaching course | tpmh0126 |
| Files to replicate TERM-BR simulations reported in Ferreira Filho et al. (2015) | tpmh0144 |
| Dynamic aggregation of SinoTERM with increasing household subsistence quantities over time (see Section 3.3) | tpgw0169 |
| Guide for potential subscribers of SinoTERM365 | tpgw0172 |

Notes: (a) The URL for all resources in the table is www.copsmodels.com/archivep.htm.

Source: Authors' construction.

Table 14 shows freely downloadable resources concerning SinoTERM or other TERM models. These resources include TERM database generation programs, and specific databases and model ingredients for replicating published applications.

As shown in Table 2, we catalogue rather than hide data deficiencies. Yet we cannot anticipate all relevant deficiencies in such a large database. We are likely to discover some deficiencies arising from specific studies using SinoTERM365

aggregations. If the SinoTERM365 database is to be improved and updated, it will in the medium term rely increasingly on researchers within China. One reason for this is that the University of Michigan discontinued hosting the China Data Center in 2018. We relied heavily on this online resource in compiling regional data. Cyber-security concerns have also resulted in international data on electricity generation plants no longer being available.

Some model developments have already occurred in project collaboration between the Centre of Policy Studies (CoPS) and research groups within China. For example, Feng et al. (2018) built on the methodology of Adams and Parmenter (2013) to develop auxiliary greenhouse gas accounts, using a dynamic version of SinoTERM originally developed at CoPS. Our hope is that by making aggregations of SinoTERM365 available, combined with short course training, on a subscription basis (see Table 14), a growing community of users will sustain database and model developments.

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