Transportation Energy Demand and Emissions in China’s Provinces to 2030

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April 14, 2014

Abstract

We describe a method for studying the combined effects of growth, regional heterogeneity and policy on transportation in China at the provincial level, and provide baseline projections and analysis of an example policy. The method advances previous development of the China Regional Energy Model (C-REM)—a multi-sector computable general equilibrium (CGE) model of the world economy that resolves 30 individual Chinese provinces. We extend the static (year 2007) model to produce a recursive-dynamic CGE forecast to 2030, comprising provincial-level sectoral output, demand for transportation and energy, and associated CO₂ emissions. This projection carries forward the freight and passenger, road and non-road modes, as well as the household vehicle transportation sector, established in previous research.

For brevity, we study results at the level of three aggregate regions—western, central and eastern China. We note how the different characteristics of these regions affect projected transport quantities: for instance, western China has an even split between road- and non-road freight, so the former sector contributes over half of the region’s 2030 transport CO₂ emissions; while in eastern China, with large mode shares of rail and marine freight associated with goods export, road freight only responsible for one third of emissions.

Examining the effects of a 10% output tax on road modes (including household vehicle transport), we find that it has a small effect on GDP and welfare, while leading to decreases in freight activity, although in eastern China there is an offsetting increase in non-road freight. Households decrease consumption of passenger transport overall, but the effect is slightly stronger for purchased road travel, reflecting a preference for private vehicles.

We conclude by describing some applications of the newly-developed dynamic CGE projection, including representation of existing policies specific to particular provinces or transport modes.

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1 Introduction

Transportation is a rapidly growing component of China's energy system, although it currently contributes a smaller share of greenhouse gas emissions than in other countries. China's economy continues to grow rapidly, despite efforts to make growth more environmentally sustainable and shift the driver of GDP growth from investment towards domestic consumption. The transport sector participates in, and is affected by, these broader trends. Future energy demand associated with transportation raises energy security concerns, and externalities of transport activity—notably congestion and local air pollution—have prompted overlapping policy responses by central, provincial and local government actors.

In order to provide salient and credible forecasts of future transport demand and its associated energy use and impacts, it is important for models to reproduce the regional disparity within China in economic structure and levels of development. Large differences in per-capita GDP determine households' ability to purchase and fuel vehicles, which they may prefer to public or commercial passenger transport. Resources (especially coal), light and heavy industry, and services have very different shares of output in each province, and demand freight transport services in different degree. Provinces also differ widely in levels of development, a gap that central government policy aims to address.

This paper contributes a methodology and baseline projections for studying the combined effects of growth, regional heterogeneity and policy on transportation in China at the provincial level. We also demonstrate how several representative policies enacted nationally, or at the level of individual provinces, impact the transportation sector.

2 Method

We employ the China Regional Energy Model (C-REM), a multi-sector, multi-region computable general equilibrium model of China's economy, benchmarked to Chinese economic data embodied in an underlying social accounting matrix (SAM), which is supplemented by physical accounts of energy, CO₂ and non-greenhouse gas emissions. The model data—SAM contents including sectoral production by region, Chinese domestic and international trade, and associated energy accounts—are developed from the GTAP 8 data base (Narayanan G. Et al., 2012) for non-Chinese regions, and China's provincial input-output tables and the energy balance tables of the 2007 China Energy Statistical Yearbook, all in the year 2007. Zhang et al. (2013) give further description of the procedure for producing balanced economic, energy and emissions data from these sources, as well as the constant-elasticity-of-substitution (CES) functions for production in energy- and non-energy sectors, consumption preferences for representative households in each region, differentiation of traded goods by the Armington assumption, and other details.

A static version of C-REM (calibrated to 2007 data) has been described (Zhang et al., 2013), and has been applied to study transportation and its energy demand through addition of sectoral detail in the transport sectors. Kishimoto et al. (2013) contains details of the disaggregation of transportation into the following subsectors, with the household vehicle transport (HVT) representation conducted according to the method of Karplus et al. (2013):
2.1 Recursive-dynamic CGE implementation

To project growth in economic activity and energy demand that is differentiated across provinces, we extend the static version of C-REM by adopting a recursive-dynamic formulation in which savings and investment—and all substitution behaviour of sectors and representative households—are based only on currently-period variables, as opposed to a forward-looking dynamic CGE formulation in which such decisions incorporate assumed perfect knowledge of future economic condition; or stochastic formulations in which uncertainty in such foreknowledge is treated explicitly (Morris, 2013). Our formulation is similar to that used in other energy-and-emission CGE models, including the MIT United States Regional Energy Policy (USREP) and Emissions Prediction and Policy Analysis (EPPA) models (Paltsev et al., 2005; Rausch et al., 2011, 2010).

Dynamic updates occur between periods in which the static numerical model is solved. The periods are in five-year time steps, except the first, which is in 2010, or three years after the base year. Exogenous parameters which vary across these periods capture the natural evolution of economic growth and the energy-using and emissions-producing nature of production. We assume a steady-state growth with Harrod-neutral technological progress for each province of China.\(^1\)

Parameters employed in this work are those governing the labour supply; and those related to non–price-induced, technologically-driven changes in the quantity of energy required for production. Labour, a factor of production, grows according to two trends: change in population (the labour force), and the augmentation of individual worker productivity, in part due to technology improvement. The population of international regions and China (in total), are derived from the long-run forecasts of the United Nations (UN Population Division, 2010). Within the Chinese total, we additionally adopt a modified gravity model to represent migration between Chinese provinces—which has been significant with progressive loosening of its hukou system of registration (Bao et al., 2011). In addition to allowing substitution which may reduce the energy share of inputs to any sector, the energy intensity of the intermediate supply from energy sectors to other production is given an increasing, exogenous time trend, to represent changes in energy intensity related to country development but not full attributable to the effects of energy prices (Paltsev et al., 2005; Schmalensee et al., 1998). This is termed an autonomous energy efficiency improvement (AEEI).

In the 2007–2010 dynamic update, we adjust these exogenous variables to match model outputs to observed increases in GDP and energy demand,\(^2\) with reference to actual 2010 population and energy demand data, and calibrate the parameters for labour productivity

\(^1\)Though this is a strong assumption, it greatly simplifies the model data requirements, without losing the general trend of economic growth.

\(^2\)That is, improved energy intensity, which in 2007–2010 in China was significantly impacted by command-and-control policies including the reduction of overcapacity and retirement of older industrial facilities.
growth and AEEI accordingly. Thereafter, the individual provincial rates of labour productivity increase, and AEEI, revert towards 2.0 per cent per annum, the long-run figures used for China as a whole in previous recursive-dynamic CGE work for China (Paltsev et al., 2012, 2005; Qi et al., 2013). Kishimoto et al. (2014) discusses the consequences of alternative assumptions for these parameter values in this new model framework.

Further assumptions concern depletion of natural resources, and land use and productivity change, both of which affect factor supply to production in subsequent periods. Especially for non-Chinese regions, these are adopted from the MIT EPPA5 model; within China, they are disaggregated or shared to provinces according to SAM data and other information on the geographical distribution of natural resources.

2.2 Transportation forecast & counterfactual policy analysis.

The recursive-dynamic C-REM projects supply and demand according the exogenous parameter updates, capital accumulation, population increase and other factors calculated to replicate conditions in future years. The model solution includes output levels in economic quantities (constant 2007 US dollars) for all industrial sectors, intermediate demand, trade and consumption. By associating benchmark physical quantities including energy and emissions with indices of sectoral activity (all unity in the base year), a baseline forecast is produced for the supplementary accounts that exist in the static model. Where economic activity grows, so do energy demand and emissions.

We augment this forecast to include quantities specific to the transportation subsectors: activity levels in the units listed in Table 1, as well as the stock of household vehicles. Thus transport activity is projected through 2030 for each Chinese province, within a full-coverage, multi-regional framework in which freight transport is supplied to meet the demand of other, growing industrial sectors; and households increase their consumption of transportation services within budgets that grow with their factor income.

Lastly, to demonstrate counterfactual policy analysis within the dynamic framework, we implement an example policy representing a tax on road transport modes. This includes a ten per cent tax on diesel and gasoline (OIL sector) input to household vehicle transport, and an output tax of 10 per cent on the road freight and road passenger sectors. The policy begins in 2015 and continues through 2030; tax revenue is collected by a representative agent (i.e. government) and remitted to households.

3 Model results

3.1 Economic, energy and transportation quantities

Figure 1 presents the top-line projection at the provincial level in economic units. Given the structure of the CES production functions underlying the model and the lack of province-specific policy, rates of growth tend to be equal across the economy (both provinces and sectors) with particular model periods. The average annual growth rates of GDP decrease over the model forecast from 6.8–7.1 per cent in 2015–2020 to 4.5–4.8 per cent in 2025–2030. The decrease is slowest for western China; it grows slowest at the beginning and fastest towards the end of the forecast period. However, this thin advantage is insufficient to overcome the initial disparity in per-capita and absolute GDP; the range of per-capita incomes in central and western provinces in 2030 matches that of the eastern provinces 20 years earlier, in 2010, and the western provinces only contribute 6.3% of China’s GDP at the end of the forecast.
Figure 1 – Provincial & regional-level GDP forecast. Left—sum of regional GDP; center—average annual growth rate (AAGR) of GDP for the model forecast periods; right—individual provinces’ per capita GDP (not summed), colored by region.

Figure 2 – Provincial level transport activity forecast. Top row—total activity by mode, in either tonne-kilometres (freight modes) or passenger-kilometres (passenger mode) per year; bottom row—per-capita passenger travel distance, by mode.
Figure 2 displays physical units, including freight tonne-kilometres and passenger-kilometres by road and non-road modes, and thus the relative importance of modes in each region in the base year and throughout the forecast. In all regions, road freight gains 1–2 per cent of mode share over the forecast period, with non-road freight maintaining a larger share. In passenger travel, the ordering of the modes—road, non-road, private in western and central China; road, private, non-road in eastern China—are also preserved.

The per-capita levels of private vehicle travel in 2030 in western and central China indicate a consistent income-ownership relationship, given their similar levels of per-capita GDP in that period. While eastern China has a much higher—almost double—individual travel distance in private vehicles and in road vehicles, households there purchase less non-road transport than even those in western China.

Figure 3 gives more detail regarding household vehicle transport, including the stock of vehicles and income-ownership relationship. Despite increasing the share of consumption devoted to transport to the highest value employed in (Kishimoto et al., 2012), the absolute stock projection does not keep pace with observations through 2012. The income-ownership trend illustrates that income gains outside of eastern China, while equal in relative terms, are small in absolute terms. It is 2020 (central China) or 2025 (western China) before the per-capita income in these other regions nears the 2010 value in the east, at which points vehicle ownership is higher than it was for eastern China at similar levels of income.

Figure 3 – Household private vehicle transport forecast. Left—total stock of private vehicles by region, with NBSC data. Right—vehicle ownership vs. GDP per capita, each marker one model period in sequence from bottom-left to top-right, with policy scenario values as thin lines.

Figure 4 plots both fuel energy use (all model fossil fuel types) and CO$_2$ emissions associated with each transport sector. In comparison with Figure 2, the energy demand reflects the higher energy intensity of road transport modes, as calibrated. Non-road pas-

Note that quantities in Figure 2 are not stacked, while those in Figure 4 are additive; the top line is the regional total.
senger transport, in particular, has a small share of emissions given its importance in western and central China, indicating the opportunity for further energy demand reduction by policies which encourage travel to shift away from road modes—both in those regions and in eastern China.

Such shifts would also reduce the demand for the liquid fuels which supply energy to the road transportation sectors. The difference in energy inputs between the road sectors and the non-road passenger and freight sectors also affects their CO$_2$ emissions shares. Coal (COL), natural gas (GAS) and electricity (ELE) use in transportation is concentrated in the non-road modes, and the relative carbon intensities of these energy sources—coal greater than oil, gas lower, electricity varying depending on the generation mix and quantities of renewables on provincial or regional grids—results in emissions contributions slightly different from shares of energy demand. Non-road freight, in particular, reflects the use of natural gas and electricity which, in central China (including the wind-rich northern provinces), is less carbon intensive than oil.

![Figure 4](image)

**Figure 4**—Top row—energy demand of transportation subsectors. Bottom—CO$_2$ emissions from transportation sectors. Vertical scale for western China exaggerated to show detail.

### 3.2 Policy scenario

We turn now to the effects of the road mode tax policy. Since the revenue from the tax is returned to households for other consumption, the effect on GDP and households’ welfare is small—less than one per cent of the baseline level. **Figure 5** gives changes in the transport activity quantities throughout the dynamic policy scenario, relative to their levels in the baseline projection. Non-road freight is the only transport sector which, under this policy,

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*In this section, “per cent decrease” means a change relative to the baseline projection. In the policy scenario, all quantities continue to grow throughout the forecast period; for instance, the decrease from 100 per cent in 2010 to 95 per cent of baseline non-road passenger transport activity in 2015 (the first year of the*
shows an increase in activity relative to the baseline, and only in central and eastern China. In eastern China in particular, this indicates the initial decrease of 9.2 per cent in road freight is offset by more rapid growth in non-road freight, which has a larger mode share. In central and western China, the policy slightly decreases the overall rate of growth.

Household vehicle transport and non-road passenger transport are equally affected in each region with an initial decrease of 4.9–5 per cent, increasing to 6.7–7.1 percent by the end of the forecast period, while purchased road transport is the passenger mode decreased most by the policy instrument—7–7.2 per cent initially.

Returning to Figure 3, the per-capita ownership and -GDP levels in the policy scenario are given alongside the baseline values. The absolute impact of the policy instrument does increase gradually from 2015 to 2030 in all regions, but does not alter the relative courses of ownership growth across the three regions—eastern and western China still exhibit higher ownership (in that order) at equivalent income levels, but lower ownership overall at the forecast horizon.

Finally, regarding greenhouse gas emissions, Figure 6 shows the policy-induced variation in CO₂ emitted from the transportation sector. Differences from Figure 5 are evident as a result of fuel shifting. Non-road freight in central China displays a larger increase in CO₂ emissions than in activity when the policy takes effect, as reduced demand for OIL (policy) occurs as the baseline itself grows 73–86 per cent over the same period.
for road freight, road commercial passenger, and private vehicles reduces the price of that fuel, allowing it to substitute for other, less carbon-intensive energy sources also used in that sector. Non-road passenger transport in both central and eastern China shifts in the opposite direction, with emissions 5.2 per cent below baseline in 2015, while activity is only 5.0 per cent below baseline.

4 Discussion and conclusions

While the baseline forecast mostly preserves the characteristics of the regions to which we aggregated province-level model outputs, the relative impact of a transport-focused policy differs by mode and region. In particular, the eastern provinces, though more dependent on passenger transport on private vehicle, appear to have options for mode shifting in both passenger and freight activity—or, in the very least, the wealth—to experience smaller impacts under the policy instrument studied in this paper. Another potential driver of this disparity is that increased production of export goods from central and western provinces needs to leave China—while CREM has no restrictions on geographic endpoints of trade, existing flows are embodied in the benchmark data on interprovincial trade and the high level of rail and shipping activity in eastern provinces, and with small rates of growth these may accommodate increased exports.

Further examination of the details of the provincial forecast and sensitivity analysis will help identify the relative importance of such dynamics. Knowledge of this sort is important to local, provincial and central government policymakers, who must understand how different characteristics of regional, provincial or municipal economies and transport systems cause them to respond differently to environmental, energy and economic policies, even when those policies are uniform across the country.

Besides offering increased detail compared to previous recursive-dynamic CGE forecasts of Chinese transport that treated the country as a whole (e.g. Kishimoto et al., 2012), and previous static regional analysis, this work also provides a foundation for studying policies which have different incidence across provinces and transport sectors. Policies on vehicle tailpipe emissions, fuel quality, private vehicle ownership, public transport infrastructure and equipment expansion, alternative fuel vehicles and many others display this sort of cross-provincial variation.

Our results also suggest regional detail is important when considering the course of growth which gives rise to the environmental burden, energy imports, traffic congestion and other transportation impacts which motivate such policies. For instance, the 2011 World Energy Outlook (International Energy Agency, 2011) gives a figure of about 0.3 vehicles per capita for China as a whole in 2035. While this may be consistent with our 2030 results for eastern China or wealthier provinces in other regions, it seems unlikely to come true.

Finally, the work points to some possible refinements and applications. In particular, adoption of the methods of Karplus et al. (2013) for representing alternative powertrains in household vehicle transport, and carefully parameterizing the cost of increasing fuel economy in conventional and alternative vehicles to the current condition of the Chinese fleet, may yield lower-cost driving options that increase driving and bring the vehicle stock forecast closer in line with observations.

In addition, given the ongoing concerns about the health effects of air pollution in eastern China’s cities, the C-REM accounts of CO₂ emissions could be supplemented with air pollutant emissions from an inventory such as REAS (Kurokawa et al., 2013), in order to project how the contribution of the transportation sector will change with time.
References


Rausch, Sebastian, Gilbert E. Metcalf, and John M. Reilly (Dec. 2011). “Distributional Impacts of carbon pricing: A general equilibrium approach with micro-data for house-


A Provinces and regions of China

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Note: Hong Kong (HK), Macau (MC) and Xizhang (Tibet, XZ) are not included in C-REM.