Modeling regional transportation demand in China and the impacts of a national carbon constraint

Paul N. Kishimoto, Da Zhang, Xiliang Zhang and Valerie J. Karplus

MIT JOINT PROGRAM

SCIENCE

POLICY

GLOBAL CHANGE

MIT JOINT PROGRAM ON THE
SCIENCE AND POLICY
of **GLOBAL CHANGE**

TSINGHUA · MIT
CHINA ENERGY & CLIMATE PROJECT

The MIT Joint Program on the Science and Policy of Global Change combines cutting-edge scientific research with independent policy analysis to provide a solid foundation for the public and private decisions needed to mitigate and adapt to unavoidable global environmental changes. Being data-driven, the Program uses extensive Earth system and economic data and models to produce quantitative analysis and predictions of the risks of climate change and the challenges of limiting human influence on the environment—essential knowledge for the international dialogue toward a global response to climate change.

To this end, the Program brings together an interdisciplinary group from two established MIT research centers: the Center for Global Change Science (CGCS) and the Center for Energy and Environmental Policy Research (CEEPR). These two centers—along with collaborators from the Marine Biology Laboratory (MBL) at Woods Hole and short- and long-term visitors—provide the united vision needed to solve global challenges.

At the heart of much of the Program's work lies MIT's Integrated Global System Model. Through this integrated model, the Program seeks to: discover new interactions among natural and human climate system components; objectively assess uncertainty in economic and climate projections; critically and quantitatively analyze environmental management and policy proposals; understand complex connections among the many forces that will shape our future; and improve methods to model, monitor and verify greenhouse gas emissions and climatic impacts.

This reprint is one of a series intended to communicate research results and improve public understanding of global environment and energy challenges, thereby contributing to informed debate about climate change and the economic and social implications of policy alternatives.

Ronald G. Prinn and John M. Reilly,
Program Co-Directors

For more information, contact the Program office:
MIT Joint Program on the Science and Policy of Global Change

Postal Address:
Massachusetts Institute of Technology
77 Massachusetts Avenue, E19-411
Cambridge, MA 02139 (USA)

Location:
Building E19, Room 411
400 Main Street, Cambridge

Access:
Tel: (617) 253-7492
Fax: (617) 253-9845
Email: *globalchange@mit.edu*
Website: *http://globalchange.mit.edu/*

Modeling regional transportation demand in China and the impacts of a national carbon constraint

Paul N. Kishimoto,[*][†] Da Zhang,[‡] Xiliang Zhang[‡] and Valerie J. Karplus[*]

Abstract

Climate and energy policy in China will have important and uneven impacts on the country's regionally heterogeneous transport system. In order to simulate these impacts, transport sector detail is added to a multi-sector, static, global computable general equilibrium (CGE) model which resolves China's provinces as distinct regions. This framework is used to perform an analysis of national-level greenhouse gas (GHG) policies. Freight, commercial passenger and household (private vehicle) transport are separately represented, with the former two categories further disaggregated into road and non-road modes. The preparation of model inputs is described, including assembly of a provincial transport data set from publicly-available statistics. Two policies are analyzed: the first represents China's target of a 17% reduction in GHG emissions intensity of GDP during the Twelfth Five Year Plan (12FYP), and the second China's Copenhagen target of a 40–45% reduction in the same metric during the period 2005–2020.

We find significant heterogeneity in regional transport impacts. We find that both freight and passenger transportation in some of the poorest provinces are most adversely affected, as their energy-intensive resource and industrial sectors offer many of the least-cost abatement opportunities, and the transformation of their energy systems strongly affects transport demand. At the national level, we find that road freight is the transport sector affected most by policy, likely due to its high energy intensity and limited low-cost opportunities for improving efficiency.

The type and degree of regional disparity in impacts is relevant to central and provincial government decisions which set and allocate climate, energy and transport policy targets. We describe how this research establishes a basis for regional CGE analysis of the economic, energy and environmental impacts of transport-focused policies including vehicle ownership restrictions, taxation of driving activity or fuels, and the supply of public transit.

Contents

[*]Joint Program on the Science and Policy of Global Change, Massachusetts Institute of Technology, MA, USA.
[†]Corresponding author (e-mail: pnk@MIT.EDU).
[‡]Institute of Energy, Environment & Economy, Tsinghua University, Beijing, P.R.China.

1. INTRODUCTION

China has replaced the United States as the world's largest auto market, and transport contributes an increasing share of its energy use and greenhouse gas (GHG) emissions. Yet motorization proceeds unevenly, as heterogeneity in household income growth across provinces affects travel and transport-related consumption. **Figure 1** illustrates this heterogeneity during the pe-
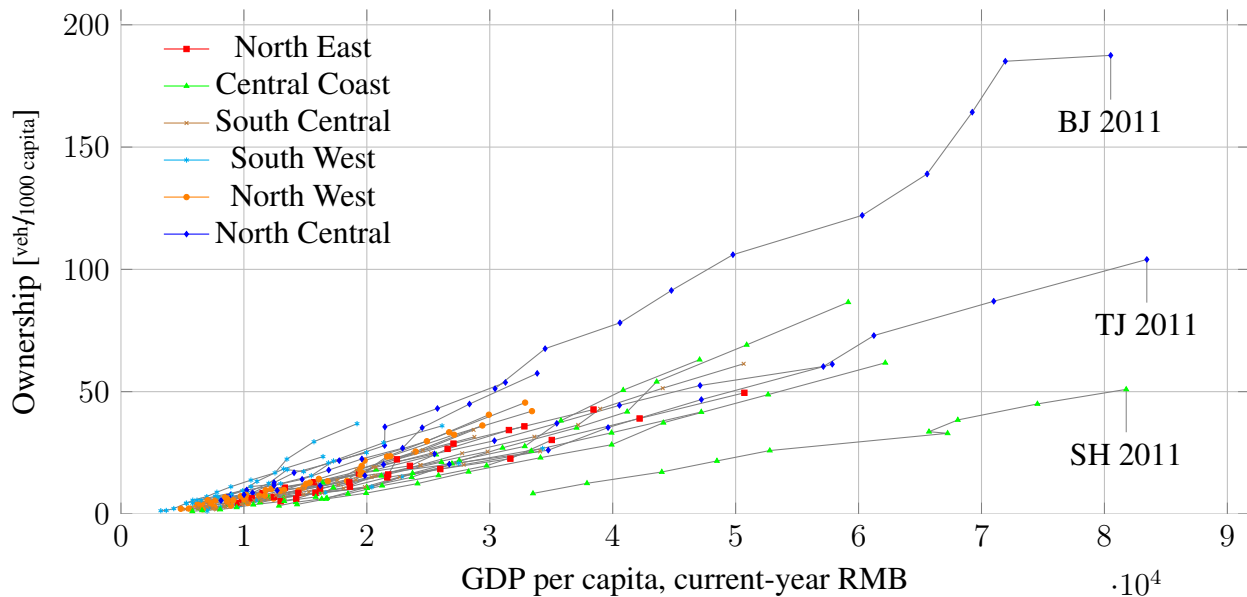

Figure 1. Private passenger vehicle ownership of Chinese provinces, 2002–2011. Annual data points for each province are connected to show trends in increasing GDP and ownership over this period. The three provinces with highest per-capita GDP are labelled: Beijing, Tianjin and Shanghai; for the regional grouping, see Figure A1. Data collated from China Communications & Transportation Association (2008) and National Bureau of Statistics of China (2008) and earlier and subsequent editions from 2003 to 2012 inclusive.

riod 2002–2011 as it pertains to ownership[1] of private vehicles. The most recent data show an order of magnitude between the provinces with lowest and highest ownership. Three of China's provincial-level municipalities—Beijing, Tianjin and Shanghai—have similarly high per-capita

---

[1] By 'ownership' we always intend the number of vehicles *per capita*; 'stock' is used for the *total number* of vehicles.
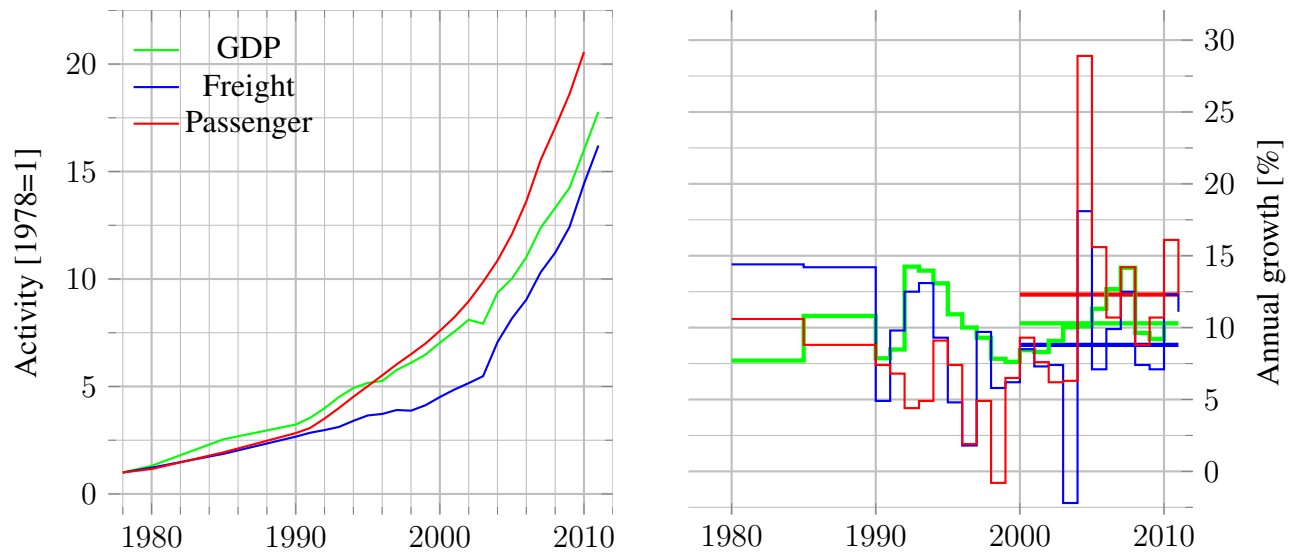
Figure 2. Left, historical growth in overall Chinese passenger and freight transport activity, indexed to activity in pass.·km or t·km in 1978, and GDP. Right, annual growth rates, with the 2001–2011 average.

gross regional product (GDP[2]) but widely different ownership. Finally, growth in income and ownership over the last decade has been rapid, as has growth in other transport activity (**Figure 2**).

Freight transport is also closely related to China's energy system and economy. The coal that supplies a large share of industrial and electrical energy is moved by rail from domestic mines or imported by sea; goods for domestic consumption or export are moved by a variety of modes, and freight traffic is commensurate with China's large quantity of exports.

Previously, we investigated household vehicle transport using a recursive-dynamic computable general equilibrium (CGE) model which represented China as a single region, and found that CO_2-intensity targets have very modest impacts on China's transport sector, on average. Reducing emissions intensity of GDP by 17% every five years results in a passenger activity reduction of less than 8% by 2050 relative to a no-policy baseline, as baseline activity more than triples from 2010 (Kishimoto *et al.*, 2012). Recognizing that national-level analysis omits the regional differences described above, and also the contribution of freight to total transport activity and energy use, we have undertaken the regional CGE modeling described here. We demonstrate the new analysis capacity by examining differences in the provincial impact of two national policies on emissions intensity of GDP.

Our findings illustrate the importance of a regional approach. Some of China's poorest provinces rely heavily on energy-intensive resource and raw materials exports, and are most adversely affected by the national-level instruments we study, in part because they offer least-cost abatement opportunities. At the national level, we find that of all the transport-related sectors, road freight transport activity is affected most by policy, likely due to its high energy intensity and limited low-cost opportunities for improving efficiency. Throughout, significant heterogeneity in regional

---

[2] We use 'GDP' for both China's domestic product and that of individual provinces, sometimes called a Gross Regional Product (GRP), including in the China Statistical Yearbooks.

conditions and outcomes motivates attention to provincial detail in further analysis of China's transport system.

The paper continues as follows: the remainder of the introduction surveys trends of the Chinese transport system, and transport-related policies in place or under discussion, including recent analysis from the literature. Section 2 includes a description of the China Regional Energy Model (C-REM) developed for this research (Section 2.1), methodology of new transport sector disaggregation (Section 2.2), and the preparation of a data set of transport activity and energy quantities (from publicly-available statistics and other literature estimates) which we use to calibrate the new sectors (Section 2.3). We then outline our policy analysis (Section 3.1), and detail our findings, first regarding changes at the national level (Section 3.2) and then regarding variation in response across regions (Section 3.3). Section 4 discusses implications of our results, and also planned future work (Section 4.1) which builds on the new regional modeling capacity.

1.1 Chinese Transportation Growth & Policy

Figure 2 shows the strong trend of historical growth in transport activity in China. The decade ending in 2011 saw an average 8.8% annual growth in freight tonne-kilometres and 12.3% annual growth in passenger-kilometres. The freight transport rate reflects strong, underlying GDP growth, while the passenger rate also includes changes in mobility behaviour of consumers as their per capita income has increased. The drivers of transport activity growth are projected to continue into the future, although there is considerable uncertainty in how they will emerge as changes in specific transport indicators (Kishimoto, 2012). For instance, while Xinhua News Agency (2012) reports that the total private vehicle stock in China will grow to 350 million in 2030 from 50 million in 2010, our own previous recursive-dynamic CGE work agrees more closely with the lower bound of projections by M. Wang *et al.* (2006), with a figure closer to 240 million in 2030 (Kishimoto *et al.*, 2012). Whichever figure is realized, the magnitude of increases in all modes will be large.

Along with freight and passenger activity growth, the impacts and externalities of transport—including high oil demand, congestion (of both road and non-road systems, and especially in cities), and local air pollution—have become policy concerns for Chinese governments. Non-transport-specific policies arising from national economic objectives also interact with China's transport sector. Aside from the national climate policies we discuss later, freight transport activity and patterns change with the export of goods, which will in turn be altered by plans to shift away from export-oriented manufacturing to growth driven by services and domestic demand (Qi *et al.*, 2012). Rail freight is also the predominant mode for moving the large amounts of coal used in China's industrial and electric power sectors between domestic locations of extraction and use.

China has designated vehicle manufacturing as a "pillar industry" (Steinfeld, 2008), and arranged joint ventures (JVs) between foreign manufacturers and domestic firms in order to improve productive capacity and encourage technology transfer (Nam, 2011). At the same time, concerned with a high reliance on oil imports (59% as of 2010, Daojiong, 2006; Xinhua News Agency, 2012), the government has moved to set aggressive targets for vehicle fuel economy (Hu *et al.*, 2010; Oliver *et al.*, 2009), and heavily subsidized the purchase of both consumer and

commercial "New Energy Vehicles" (NEVs, elsewhere sometimes referred to as "alternative fuel vehicles"). Gong *et al.* (2012) note that this latter effort promotes the development of advanced vehicle technology—yet has resulted in only limited progress towards sales targets. Among other factors, the post-subsidy cost of NEVs may still compare unfavourably with other options for motorizing households. For long-distance passenger transport, airports and a national, high-speed rail network have been expanded rapidly through direct government spending (Campos *et al.*, 2009).

At the provincial and municipal level, transport externalities including air pollution (Sun *et al.*, 2004) and congestion are acute concerns. Although walking, cycling, and two-wheel electric vehicles retain a non-trivial mode share in Chinese cities (Peng, 2004; Weinert, Ma, *et al.*, 2007; Weinert, Ogden, *et al.*, 2008), their regulation appears to be a less pressing policy concern. Instead, the negative consequences of growth are often addressed through policy entrepreneurialism (Chien *et al.*, 2011), with decision makers studying historical international and recent domestic responses to similar problems while experimenting with a variety of measures. For instance, in the capital, Beijing, and China's largest city, Shanghai, policies have been enacted which limit the sale of new vehicles by auctioning license plates, or awarding them by lottery (Hao *et al.*, 2011); other cities are actively studying the effectiveness of these measures and considering hybrid systems (Caixiong, 2012). Policies on retirement of old vehicles, cordon exclusion of high-polluting vehicles (including certain classes of freight vehicles), and the limitation of driving through rotating bans, pricing and/or tolls have been tried in different locations (Hao *et al.*, 2011; Suen, 2012; Yin *et al.*, 2011). To affect the fuels used in both freight and passenger road transport, some regions have taken the initiative of adopting standards more stringent than those set nationally (Xin, 2012). Municipalities have taken advantage of high subsidies and new financing opportunities including public-private partnerships to increase the supply of subways and other public transport (de Jong *et al.*, 2010; Y. Wang *et al.*, 2011).

Viewed next to the differences in statistical characteristics of provincial transport detailed below in Section 2.3, the extensive suite of unevenly-applied policy instruments with sometimes countervailing purposes suggests that impacts may differ across provinces and targeted transport sectors. Motivated to represent these effects in a CGE model that can also capture the interaction of transport sector energy transformation with the rest of the Chinese and world economy, we undertook the modeling effort described in the next section.

2. METHOD

2.1 The China Regional Energy Model (C-REM)

The C-REM is a multi-sector, multi-region static numerical computable general equilibrium economic model of the world. Thirty Chinese provinces are represented individually, along with six international regions (**Table 1**). Sixteen sectors are represented, including main types of primary energy, electricity and—prior to this research—*all* transportation (**Table 2**). Like the MIT United States Regional Energy Policy (USREP) and Economic Projection and Policy Analysis (EPPA) models (Paltsev *et al.*, 2005; Rausch *et al.*, 2010), the C-REM includes supplemental physical accounts of energy and GHG emission quantities to support analysis of policies which

Table 1. Regions in the C-REM.

Code	Region
---	*(30 individual Chinese provinces; see Appendix, **Figure A1**)*
APD	Asian and Pacific developed countries
ASI	Other Asian countries
CAA	Former Soviet Union, Central Asia and Africa
EUR	Europe
NAM	United States and Canada
ROW	Latin America, Eastern European countries, rest of the world

Table 2. Sectors in the C-REM, prior to transport disaggregation.

Code	Sector	Code	Sector
AGR	Agriculture	OID	Other industries
COL	Coal mining & processing	OIL	Refined oil
CRU	Crude petroleum products	OMN	Metal, minerals, other mining
EID	Energy-intensive industries	OTH	Other service industry
ELE	Electricity	TME	Transport machinery & equipment
GAS	Natural gas products	TRD	Wholesale & retail trade, hospitality
GDT	Gas production & supply	TRP	Transportation
LID	Light industries	WTR	Water production & supply

directly price or affect the cost of energy use or emissions. C-REM has also previously been used to simulate an emissions intensity constraint (Zhang *et al.*, 2012). The static version of the C-REM used for this research has a 2007 base year. The model is implemented in the Model Programming System for General Equilibrium (MPSGE) and GAMS, and the numerical solution found using the GAMS/PATH solver.

The C-REM social accounting matrix (SAM) is prepared using a code which makes least-squares adjustments to data from the 2007 China Input/Output Tables (China State Information Council, 2011), the 2007 China Energy Statistical Yearbook (National Bureau of Statistics of China, 2008), and the GTAP 8 Data Base (Narayanan G. *et al.*, 2012), such that economic value and physical quantities are balanced. Specific quantities may be designated as fixed and are not subject to any adjustment. These include the GTAP 8 quantities for China's national economic totals, international trade flows and all data for non-Chinese regions. However, quantities designated as fixed presently *do not* include transport sector outputs or inputs (including energy), or the household consumption that we will later assign to a new household private vehicle transport sector. Given the necessity of using adjusted statistical data—as described in Section 2.3—we have chosen not to have the balancing code hold fixed any transport-related quantities. One consequence of this is the apparent absence of household private vehicle transport in some provinces with low motorization, which we note in Section 3.2.

2.2 Transport Sector Disaggregation in C-REM

Our transport disaggregation has two aspects. By *commercial transport*, we denote the activity of the former C-REM TRP sector. The portion of this sector's output which was consumed as an intermediate in other production we assume to be *freight transport*, while the portion di-
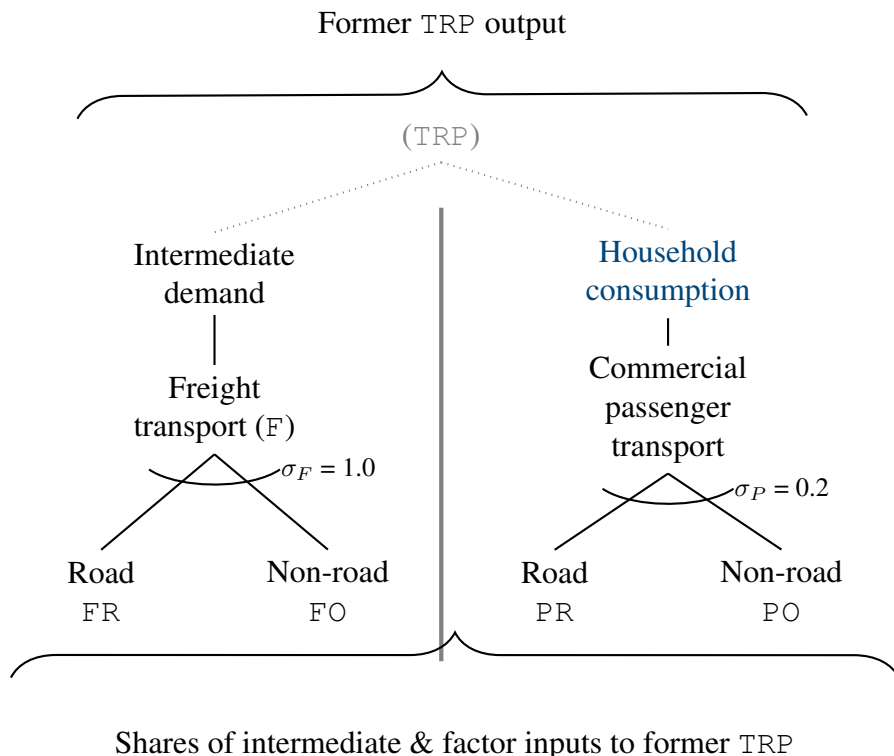
Former `TRP` output

(`TRP`)

Intermediate demand

Freight transport (`F`)

$\sigma_F = 1.0$

Road

`FR`

Non-road

`FO`

Household consumption

Commercial passenger transport

$\sigma_P = 0.2$

Road

`PR`

Non-road

`PO`

Shares of intermediate & factor inputs to former `TRP`

Figure 3. Disaggregation of the C-REM `TRP` sector. The original sector is eliminated, and all intermediate demand from other sectors is satisfied from the new non-road and road freight sectors. Inputs to the four commercial sectors are shared as described in 2.3.1.

rectly consumed by households is assumed to be *commercial passenger transport*. As shown in **Figure 3**, we further disaggregate each of these portions into road and non-road sectors, with the latter comprising rail, marine, air and (for freight only) pipeline transport. By *household transport*, we denote the consumption by households of commercial passenger transport (output from the former `TRP` sector), as well as from other sectors from which we construct a *household vehicle transport sector*. In the supplemental physical accounts, activity levels for the two freight transport sectors are in tonne-kilometres, and activity levels for the two commercial passenger sectors and the household vehicle transport sector are in passenger-kilometres. We assign each sector a new code:

Table 3. New household transport sectors in the C-REM.

Code	Sector	Activity Units
`FO`	Non-road freight	tonne·km
`FR`	Road freight	tonne·km
`PO`	Non-road (commercial) passenger	passenger·km
`PR`	Road commercial passenger	passenger·km
`HVT`	Household vehicle (transport)	passenger·km

The household vehicle transport structure is adapted from one used in the EPPA model as detailed by Karplus, Paltsev, Babiker, and Reilly (2013) and applied to China by Kishimoto *et al.*

7
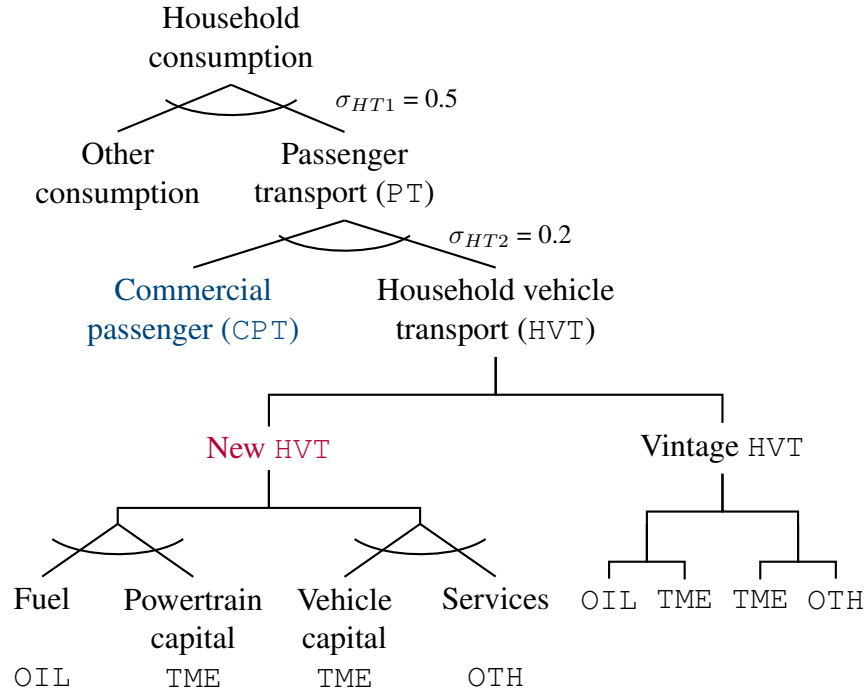
Figure 4. Structure of household consumption, including transport sector detail.

(2012) for the representation of light duty vehicle technology detail in CGE. This structure is illustrated in **Figure 4**. Households obtain an "own-supplied [vehicle] transport service" from a vehicle capital stock, which is supplied by inputs from the transport mechanical equipment (TME) and services (OTH) sectors. The capital stock is divided into two parts, one representing the non-propulsion components of the vehicle transport service. The other part, designated powertrain capital, is combined with fuel (refined oil sector output, OIL) to provide the propulsion component of the service. In response to increases in OIL price, households substitute more powertrain capital, obtaining a more expensive vehicle with improved fuel economy. They may also shift consumption to other sectors—including the two modes of commercial passenger transport—or reduce consumption. The structure separately represents the service derived from used or vintage vehicle stock, for which fuel economy is fixed.

For this research, we applied the transport disaggregation to China's provinces only, preserving the existing TRP structure for the six C-REM international regions.

2.3 Data Collection & Model Calibration

Reliable transport data are important if models are to provide credible transport policy analyses, but the statistics on China's economy, energy use and transport system present challenges in their level of detail— and sometimes questionable accuracy. Guan *et al.* (2012) famously noted a "gigaton gap" in reported CO_2 emissions—equivalent to Japan's national total—between a sum of provincial totals and the national figure given by the National Bureau of Statistics (NBS). Li *et al.* (2012) note that local and provincial officials, who are graded on a point system which includes progress on development targets, thereby face incentives to over- or under-report vari-

8
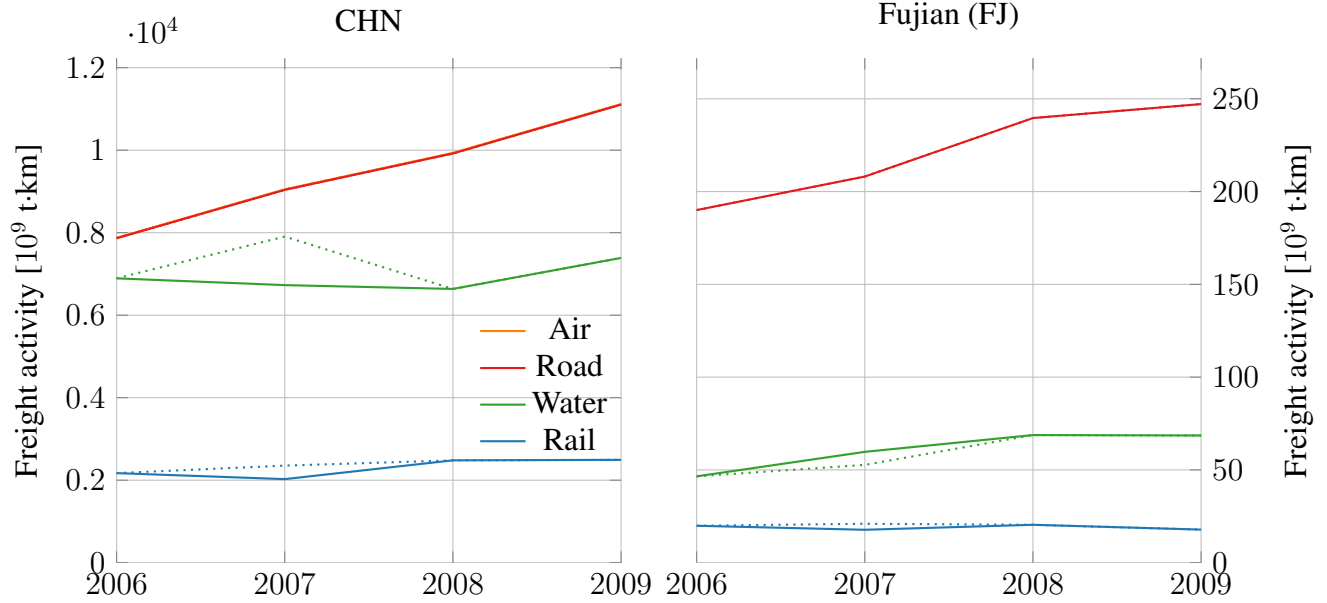
Figure 5. Freight activity in China (left) and Fujian (FJ, right), 2006–2009, showing reported (dotted line) and share-adjusted (solid line) 2007 quantities.

ous quantities. In turn, provincial statistical bodies and the NBS apply corrections for this mis-reporting or perform other adjustments, which are not documented, for a variety of sources of error (Holz, 2004).

These challenges were encountered during development of the C-REM (more detail is given in Zhang *et al.*, 2012), and again in disaggregating the transport sector for this research. Our approach was to produce a provincial data set by collating publicly-available information from NBS yearbooks (CCTA 2008; 2009 and earlier and subsequent editions from 1999 to 2012 inclusive), and examine it to identify necessary adjustments.

Coverage of data is another challenge. While supplemental transport energy and physical activity accounts for national-level CGE modeling can be based on NGO- or privately-maintained international databases such as Passport GMID, IEA World Energy Balances and the International Road Federation's World Road Statistics (Euromonitor International, 2011; International Energy Agency, 2010; International Road Federation, 2010), the analogous statistics for China, if not reported by the NBS, national ministries, or lower-level agencies, may be entirely unavailable. To correct this deficit, we turn to the extensive literature on Chinese transport energy use and emissions for conversion factors, intensities and other quantities, which we combine with adjusted statistics to produce the quantities required for model calibration.

This process is explained for commercial transport and household vehicle transport in the following two subsections.

2.3.1 Commercial Transport

Year 2008 statistics reported by the NBS show significant decreases relative to 2007 in marine freight transport activity (**Figure 5**). This could be explained as the impact of reduced Chinese
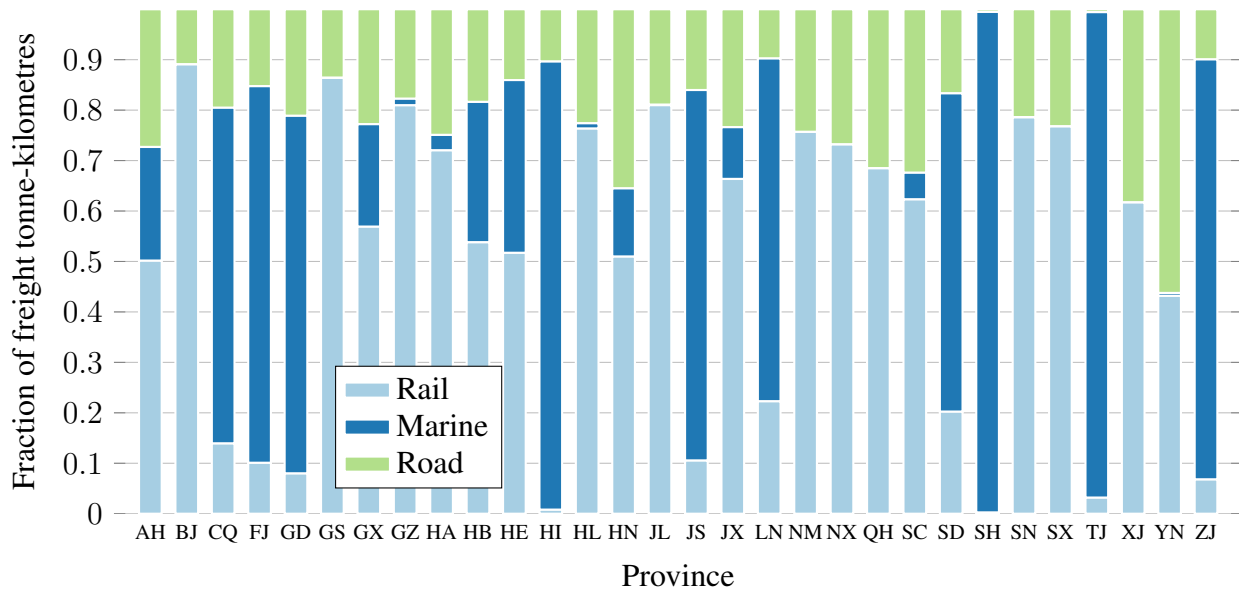
Figure 6. Adjusted mode shares of freight traffic, Chinese provinces, 2007.

exports due to falling global demand at the beginning of the 2008–2010 global recession—*except* that there were corresponding increases in road freight activity, such that the growth in overall totals remained steady from 2007 through 2009 (Figure 5, solid lines). The growth rates of individual modes have also paralleled the national total in subsequent years. We instead interpret this change as a statistical adjustment—for a former over-reporting of marine traffic, under-reporting of highway traffic, or both—and adjust the 2007 data by sharing out the total freight activity in the same proportion as in 2008, province by province (Figure 5, dotted lines). The resulting 2007 mode shares of freight and passenger traffic are shown in **Figures 6** and **7** respectively.

The China Energy Statistical Yearbook's energy balance tables report provincial transport energy consumption by fuel; there is no disaggregation by mode. The C-REM sectoral aggregation and balancing code (see Section 2.1) also aggregates some of these quantities (combining, for instance, both diesel and gasoline to `OIL` sector energy) and adjusts them along with other, non-energy inputs to transport. We estimate the energy intensity of the four commercial transport sectors `FO`, `FR`, `PO` and `PR` using the adjusted activity levels and bottom-up modal energy intensity figures from literature (see Appendix, **Table A1**), then divide `TRP` output and input among the four sectors while maintaining a balanced SAM, as follows:

1. `TRP` sector supply consumed by households is designated the commercial passenger part, and remaining supply the freight part.

    (a) `FO` and `FR` are assigned shares of the freight part in proportion to their relative activity levels.

    (b) `PO` and `PR` are assigned shares of the commercial passenger part in proportion to their activity levels.

10
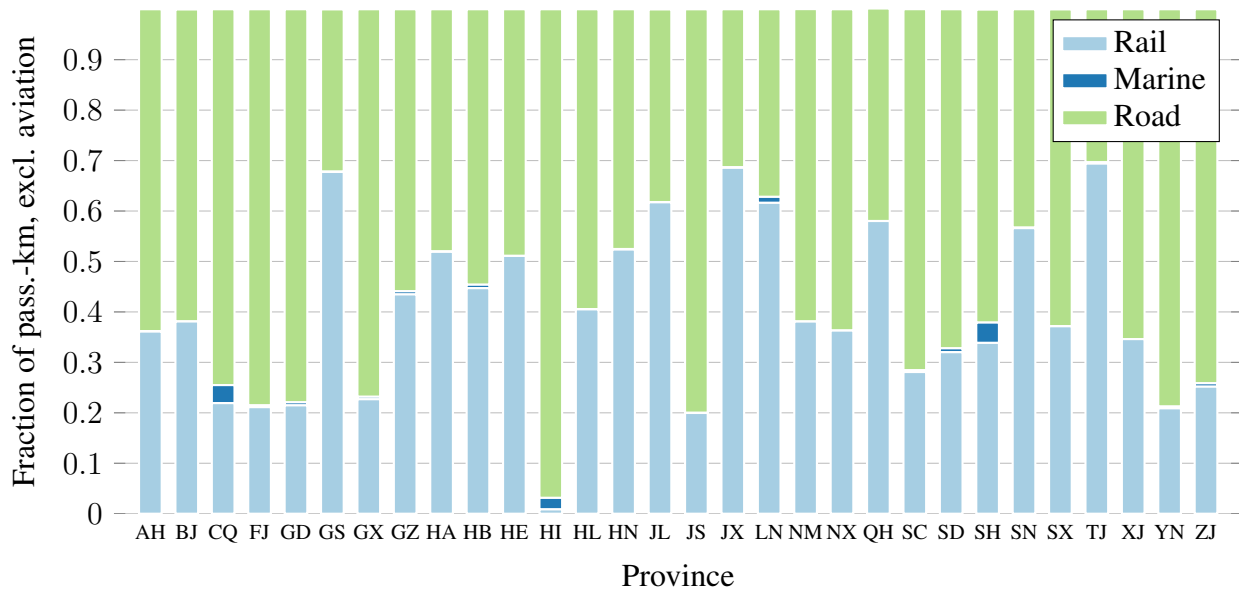
Figure 7. Adjusted mode shares of passenger traffic, Chinese provinces, 2007.

2. All `TRP` sector intermediate and factor demand is divided among `FO`, `FR`, `PO` and `PR`, in proportion to their outputs.

3. Intermediate demand from the energy sectors `COL`, `CRU`, `ELE`, `GAS`, `GDT`, and `OIL` is rebalanced between `FO` and `FR` such that their relative energy intensities match our estimate from statistics and literature. (Likewise `PO` and `PR`.)

4. Intermediate consumption of `OIL` in `FO` is reassigned to `FR`, and a corresponding sum of `COL`, `CRU`, `ELE`, `GAS` and `GDT` reassigned from `FR` to `FO`. (Likewise `PO` and `PR`.)

This final step enacts the observation that very little Chinese road transport in 2007 used non-liquid fuels such as coal, natural gas or electricity.

2.3.2 Household Vehicle Transport

Given a paucity of regional data, we assign 95% of household `OIL` consumption to household vehicle transport, and designate all `TME` consumption as vehicle capital, of which 20% is power-train capital. Because households in Liaoning (`LN`) and Ningxia (`NX`) consume no refined oil in the C-REM balanced SAM, household vehicle transport detail is omitted for these provinces.[3] In Karplus, Paltsev, Babiker, and Reilly (2013) and Kishimoto *et al.* (2012), the services (`OTH`) input to household vehicle transport is calibrated as a residual between `OIL` and `TME` consumption and data on total household expenditure on transport from Passport GMID. Since this latter quantity is not available for Chinese provinces, we assume the ratio of `OTH` to `TME` in each of China's provinces to be the same as the national average. We also adopt the assumption that used vehicles

---

[3] The absence of `OIL` consumption in the SAM for these regions is related to a very small value in the raw statistical data read into the SAM balancing code, indicating that households in these provinces contribute little to total `OIL` demand.
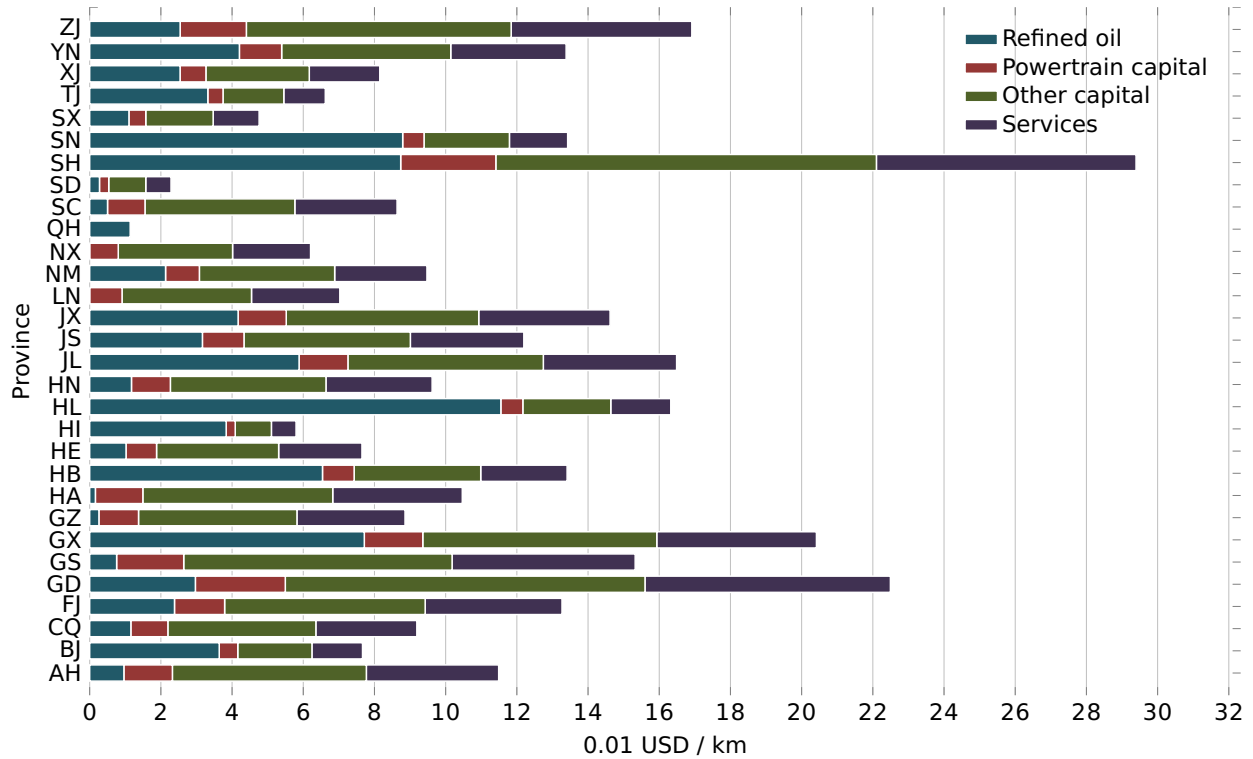
Figure 8. Calibrated components of levelized cost per distance in household vehicle transport.

provide 60% of vehicle travel, implying the fuel–powertrain capital substitution is only available for the 40% of travel from new vehicles. In future work, identifying province-by-province sources for these quantities will allow us to improve our results.

In calibrating the household vehicle transport sector, we faced an absence of comprehensive provincial private vehicle activity statistics. Instead, we constructed activity levels using the vehicle stock, an estimate of occupancy, and survey-based data on the annual distance travelled per vehicle from Huo *et al.* (2012), with national averages and specific figures for some, but not all, provinces. Dividing the sectoral input quantities to household vehicle transport by this activity level data gives their contribution to the levelized cost per distance (LCPD) of household vehicle transport, as shown in **Figure 8**. LCPD data reflect variation in several quantities across provinces, including distance travelled per vehicle and the characteristics of private vehicles. For instance, in Shanghai the large overall cost may reflect both the expense of luxury vehicles and a lower driving distance denominator. In **Figure 9**, we note that the share of household consumption devoted to transport is between 5% and 11%,[4] a similar range to Travel Money Budgets (TMB) observed for entire countries in the literature (e.g. by Schäfer, 1998).

---

[4] With some exceptions such as Liaoning and Ningxia, as discussed, and Hainan (HI, 海 南), an island province with a high share of air travel.
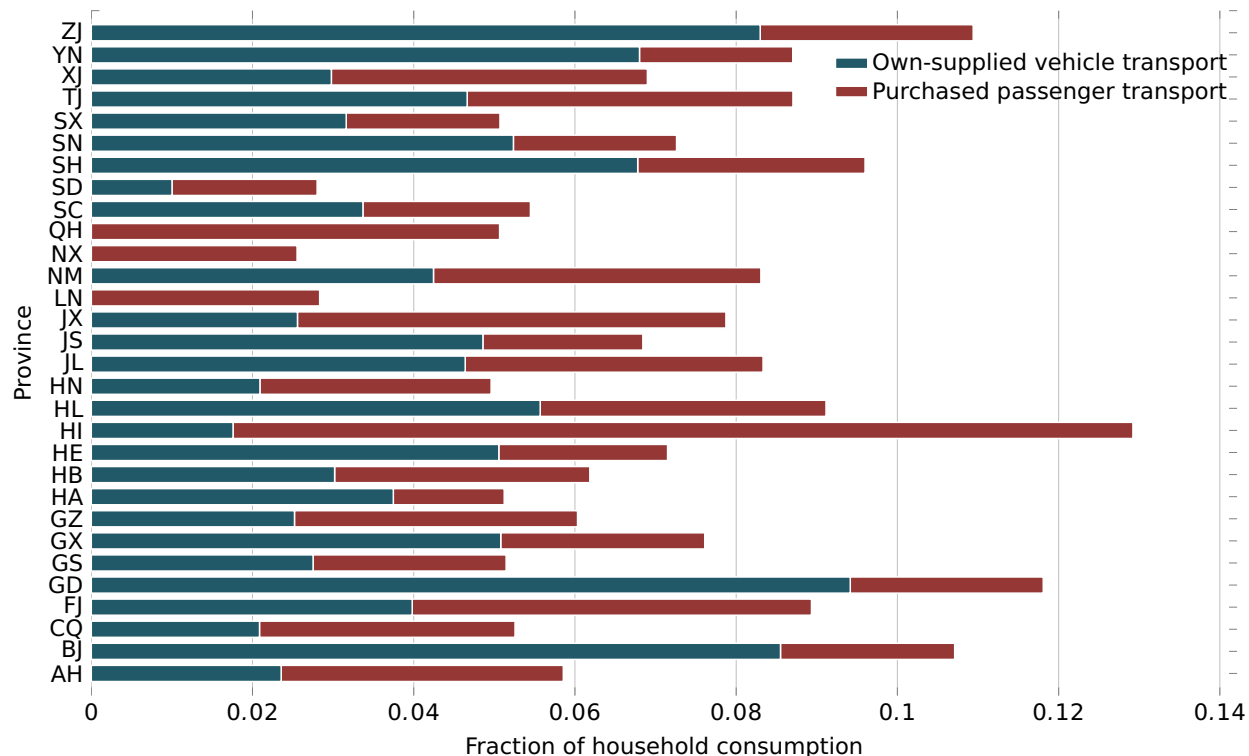
Figure 9. Calibrated share of household expenditure household vehicle, commercial road and commercial non-road transport.

3. POLICY ANALYSIS

3.1 National Emissions Intensity Policies

As outlined in Section 1.1, an extensive suite of policies using many instruments targets China's transport system and the technologies and users it comprises. We developed a transport sector disaggregation in order to support comparison of policies (some of which we anticipate in Section 4.1) which narrowly target transport modes, technologies or provinces. However, the transport sector also responds to economy-wide policy which affects the costs of energy or emissions; the character of these effects provides important context for evaluations of targeted policy. Applying economy-wide policy allows us to examine the distinct responses of the disaggregated transport sectors.

In addition to a base case, we model two policies. The first, denoted "Policy 1" or "P1" in figures, represents the 12FYP target of a reducing the GHG emissions intensity of GDP by 17% between 2010 and 2015. The second policy, denoted "Policy 2" or "P2", represents the lower bound of a targeted 40–45% reduction from 2005–2020 that China first stated at the 2009 UN Climate Change Conference in Copenhagen (UN FCCC Secretariat, 2011). This is an additional 27.3% reduction beyond the 2015 target.

To date, these policies are implemented by China's central government as provincial targets explicitly assigned such that national targets are met, with wealthier provinces (generally in the East) facing a higher reduction burden than poorer ones. However, we model the policies using

13
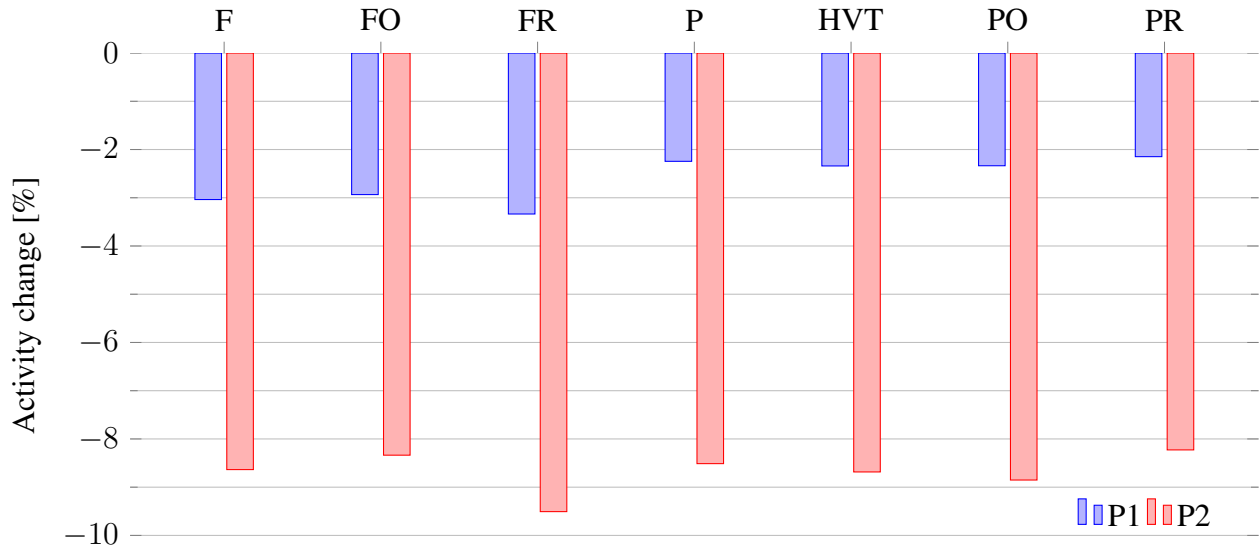
Figure 10. Impact of policy on China total transport activity levels (pass.-km or tonne-km) by transport sector, including a freight total (F) and passenger total (P).

a national-level constraint and an endogenous tax on CO_2 embodied in energy use, representing a nation-wide allowance trading market in which the provincial changes in emissions intensity depend on the relative costs of reductions across provincial economies, including their transport sectors. For details on the differences between these two implementations of a national intensity target, see Zhang *et al.* (2012).

Because we use the static version of C-REM for this research, the analysis omits future growth in the overall economy and in transport activity which, as noted in Section 1.1, is expected to be rapid. Along with growth, the relative levels of production from economic sectors—including transport sectors—in China have changed, both endogenously and as a result of deliberate policy. The static analysis assumes that the relative levels of output across sectors and provinces remain as they were in 2007.

Finally, although the *emissions* intensity instrument rewards fuel switching from high- to low-emissions intensity energy sources (for instance, from COL to OIL or GAS), for simplicity we focus mainly on *energy* intensity in the following discussion of results. Reductions in emissions intensity—of transport activity, or of output in value terms—are in line with the energy results, plus some effect of the substitution of energy sources with lower emissions intensity.

3.2 National Impacts

3.2.1 Changes in Transport Activity

We begin our discussion of results with changes at the national level. Total Chinese CO_2 emissions decreased 25.4% under Policy 1 and 47.9% under Policy 2, with values larger than the intensity constraints indicating that reductions were made in part by reducing production. Overall energy intensity decreased 16% (P1) and 35% (P2) as the carbon intensity of energy decreased 10.5% (P1) and 17.9% (P2).

14
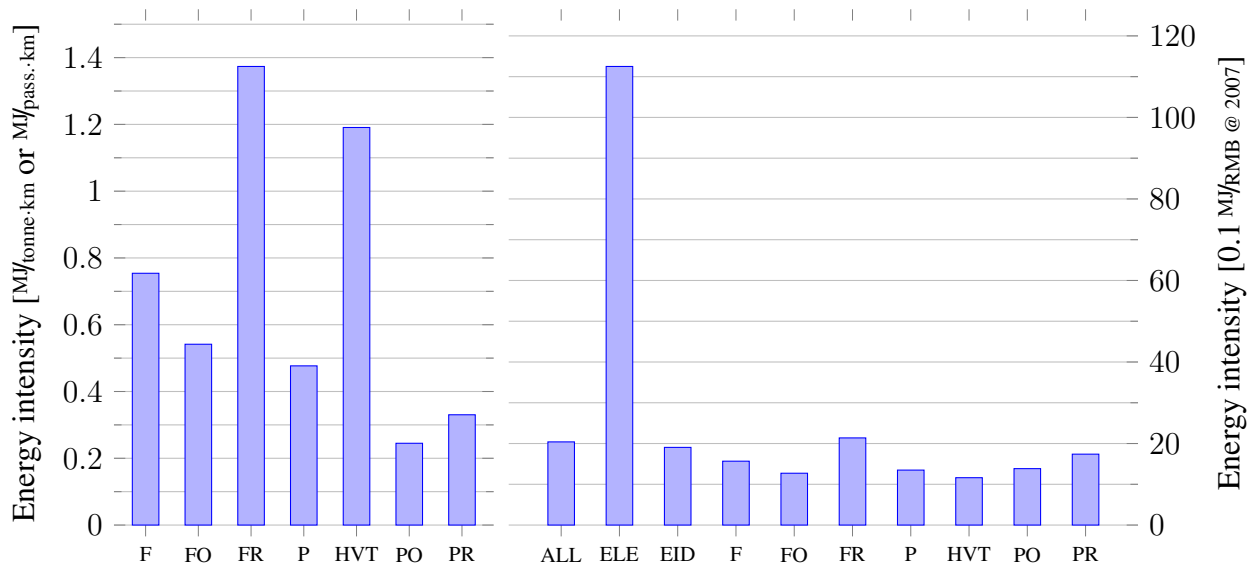
Figure 11. Energy intensity of transport modes in base year (2007) data. Left, in physical terms (per freight tonne-kilometre or passenger-kilometre); right, per unit output value and compared to the energy intensity of electricity, energy-intensive industry, and of all GDP.

Figure 10 gives changes in total China freight and passenger activity under each policy. For a 17% reduction in economy-wide emissions intensity of GDP, freight activity decreases 3.0% and passenger activity decreases 2.2%; for a 40% reduction the respective figures are 8.6% and 8.5%. In both cases road freight experiences the largest change, and household vehicle transport and non-road passenger decrease more than road commercial passenger. These changes are partly explained by examining the energy intensity of transport modes on activity and output bases, as shown in **Figure 11**. Although household vehicle transport has an activity-basis energy intensity much higher than other passenger modes, as a value-added sector with significant non-energy components it offers slightly *less* energy reduction for a given reduction in consumption of its output. In contrast, because the road and non-road freight sectors have a similar balance of energy and non-energy inputs, the high activity-based energy intensity of road freight translates to a high value energy intensity, with the observed larger share of activity reduction under national policy.

3.2.2 Comparison with Impacts in Other Sectors

In **Figure 12** we show the reductions in energy intensity by total freight and total passenger transport, compared with that in the energy intensive industry (`EID`) and electricity (`ELE`) sectors and the economy as a whole. Both categories of transport reduce energy intensity less in relative terms than the economy as a whole, indicating that transport does not offer the lowest-cost opportunities for energy use abatement. In contrast, electricity production, a highly emissions-intensive sector, undergoes a much larger energy-intensity reduction than the entire economy, and almost twice as large as passenger transport.
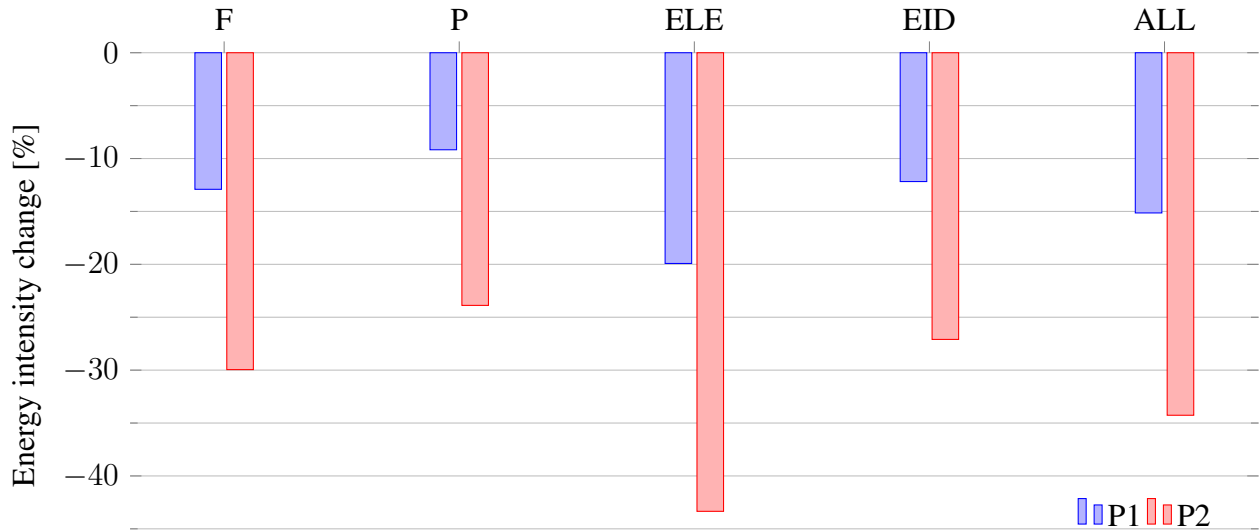
Figure 12. Energy intensity reductions in transport versus other sectors.

3.2.3 Oil Demand

Focusing on demand for refined oil products, **Figure 13** shows contributions of individual transport sectors to a total reduction of 1.2 EJ (5.1%) under Policy 1 and 3.558 EJ (15%) under Policy 2. Despite the reductions in energy intensity made by passenger modes, their contribution to oil demand reduction is small due to the low level of passenger activity relative to other oil consumption. About 40% of the reduction is made in freight modes—slightly more in road freight—and over 50% of reductions are made in non-transport sectors.

Absent any growth, national climate policy would make a significant contribution to reducing China's dependence on oil imports; however, these reductions are more than offset by expected growth in total Chinese oil demand over the periods for which the targets are set. These results indicate that climate policy impacts may help China towards energy "self-sufficiency" (i.e. limit the share of imports in oil consumption), but also suggest that policies targeted at passenger vehicles (private or commercial) may not contribute significant reductions towards such a target unless the share of oil consumed by passenger vehicles grows. Sectoral policy aimed at oil demanded by freight modes and non-transport activity, on the other hand, may have larger impact.

3.3 Provincial Impacts

3.3.1 Freight Transport

We now turn to the regional impacts of policy. In **Figure 14**, we show the provincial-level impacts of each policy on road, non-road and total freight activity by province. In both cases, Gansu (GS), Guizhou (GZ), Inner Mongolia (NM), Shanxi (SX) and Yunnan (YN) experience the largest reductions. In general, road freight activity decreases more than non-road freight activity, although this pattern is reversed in some provinces, such as Gansu, Yunnan, Guizhou, and Shaanxi (under Policy 2). Some provinces—such as Fujian and Jiangxi—experience increases in
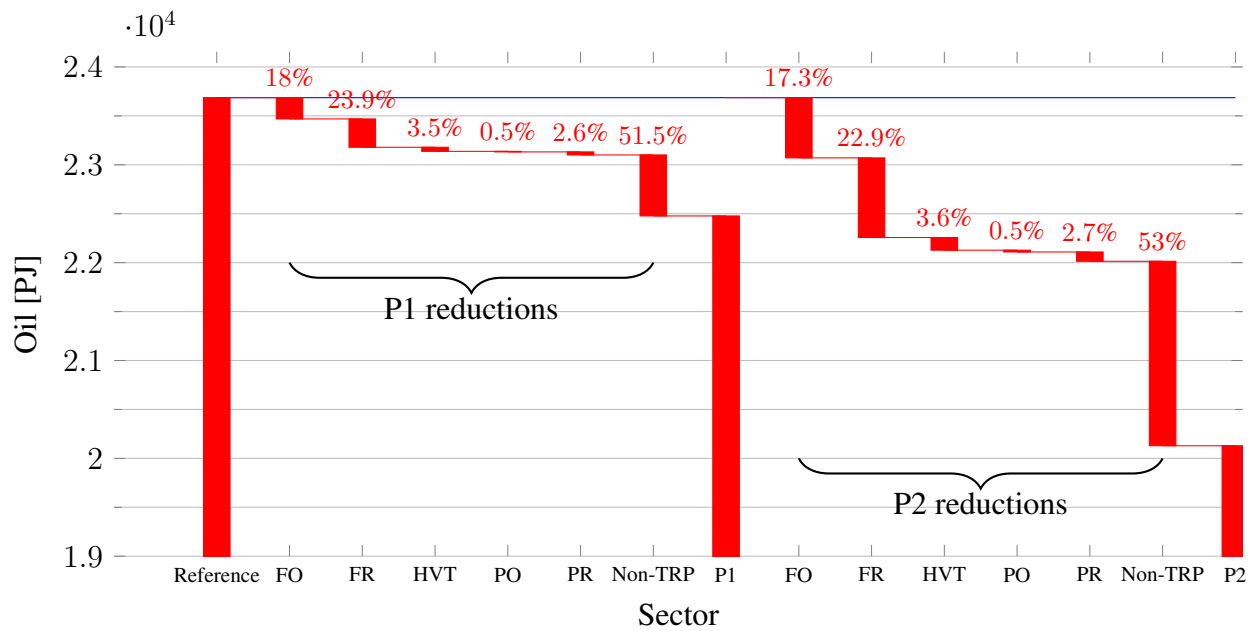
Figure 13. Contributions to oil energy demand reduction under policy from each transport sector, and the sum from all other, non-transport (Non-TRP) sectors. Labels indicate the portion of the reduction contributed by each sector; "Reference" gives the reference level of consumption; "P1" and "P2" the totals in the two policy cases.
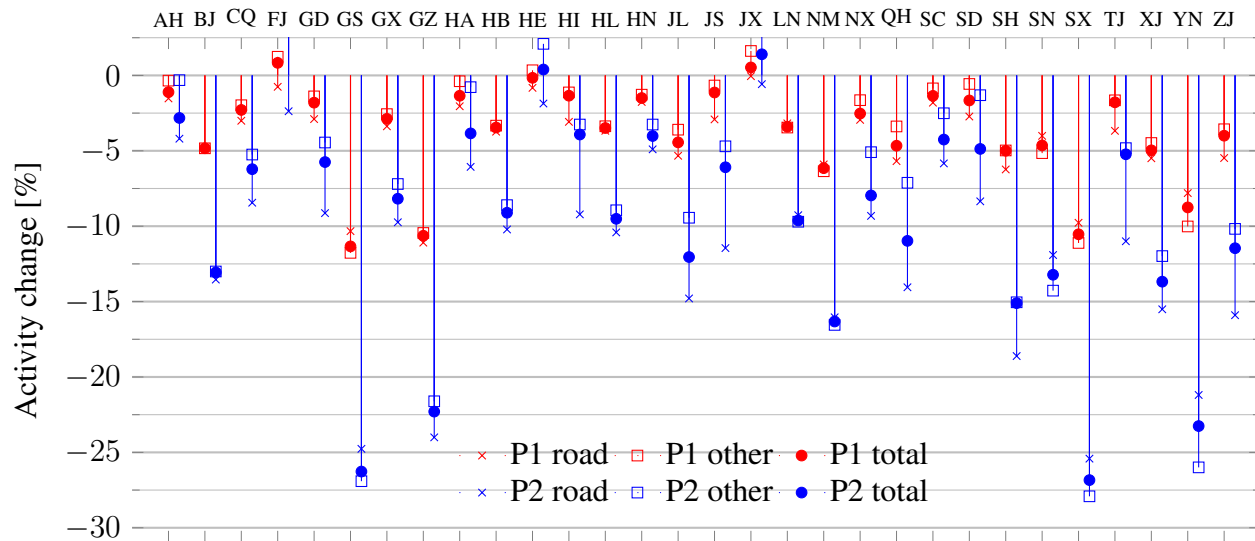
Figure 14. Policy impact on freight transport by mode and Chinese province.

freight activity in some or all modes.

To interpret these results, we turn to **Figure 15**, which compares the change in freight activity by province against four other properties: total provincial GDP, the ratio of industry (`EID`, `LID` and `OID`) output to GDP, the energy intensity of all provincial GDP and the energy intensity of the provincial freight sector. The provinces experiencing the greatest reductions in freight activity have high energy intensity of production overall (Figure 15c) although not of freight particularly (Figure 15d). They are required by the policy instrument to transform (de-carbonize) their economy to greater degrees, in turn affecting demand for freight transport. All of the above-listed provinces have relatively low CO_2 emissions abatement costs and contribute significantly to achieving the national reduction target.

3.3.2 Passenger Transport

Figure 16 shows the impacts on all three passenger modes of each policy, by province. Shanxi, Heilongjiang, Gansu, Beijing, and Xinjiang display the largest reductions in passenger transport generally, including household vehicle transport. Shanxi, in particular, reduces activity by 7.5% under Policy 1 and 23% under Policy 2, respectively 2.5 and 12 points more than the next-most-affected province, Heilongjiang. Again, there is an instance of a province *increasing* transport activity under policy (about which more shortly). Generally, tightening the intensity policy does not significantly change the share of modes between road, non-road and household vehicle passenger activity, and the activity reduction (or increase) is similar across passenger modes—an effect constrained by the substitution elasticities between the commercial passenger modes, and between these and household vehicle transport. In the case of Qinghai, transport activity decreases even with a slight consumption increase under Policy 1, then further as consumption decreases under the tighter policy.

To assist with interpretation of the passenger transport results, **Figure 17** juxtaposes the change in activity with the change in total household consumption, showing a generally strong relationship with some nuances. For the slight majority of provinces below the line of proportional decrease, a substitution away from transport to other consumption occurs in response to a reduced household budget, due to the high energy/carbon intensity of transport relative to other goods in the consumption bundle. If this relationship is symmetric, it would indicate that a situation that increased household income in these provinces—such as economic growth—would induce a shift of consumption into transport, increasing the travel money budget. For provinces *above* the line in Figure 17, the inverse relationship exists.

3.3.3 Combined Results for Provincial Transport Systems

To consider the effects on the entire transport systems of individual provinces, we return to the lens of aggregate refined oil demand for all transport sectors.

Figure 18 gives the change in total provincial oil demand, and for the combined transport sectors. Recalling the observation from Figure 13 that transport contributes about half of the national oil demand reduction, we see that in most provinces the *percentage* reduction from transport is much higher than the total percentage reduction. This relationship represents two effects: reduced
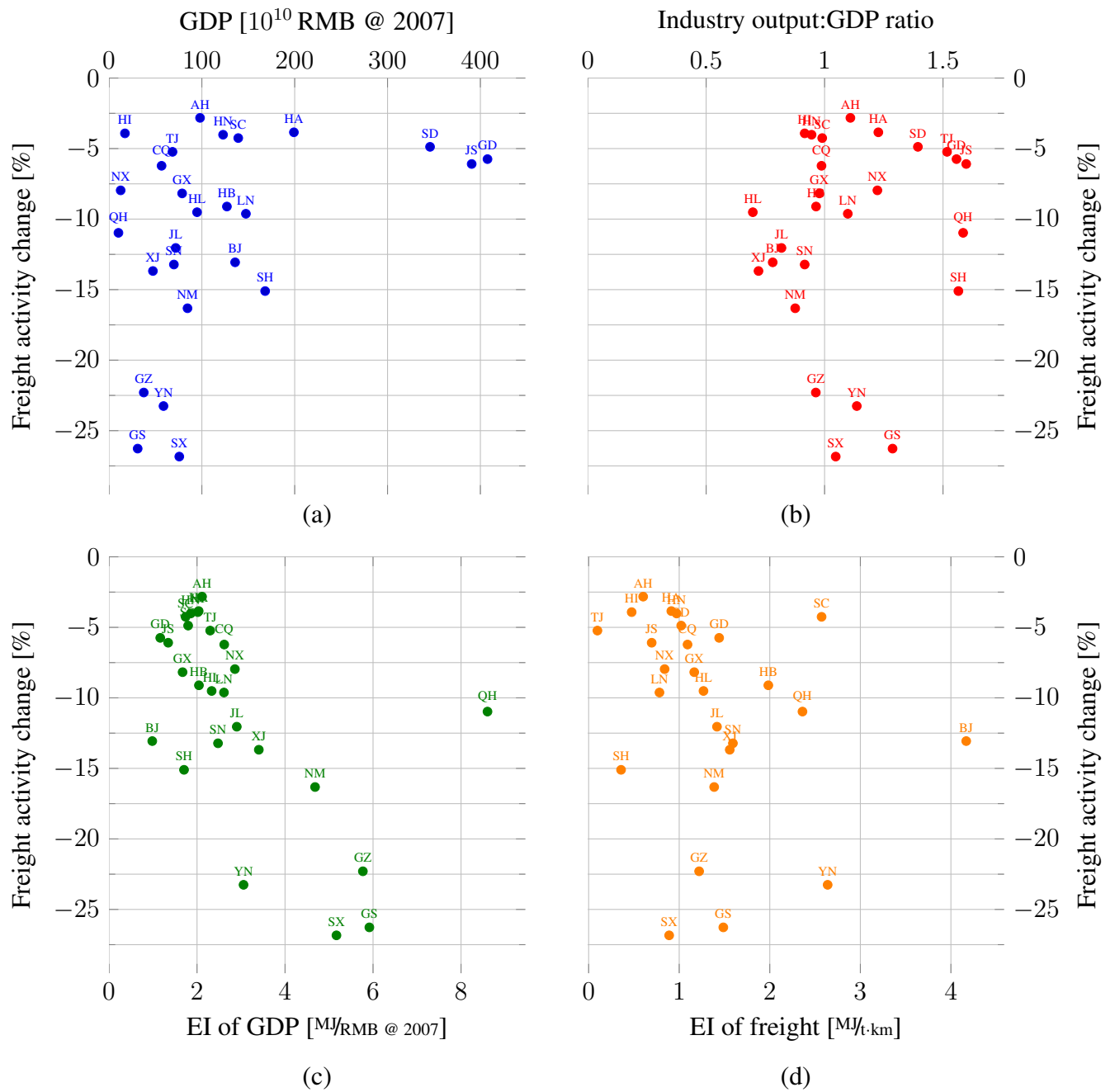
18

Figure 15. Total freight activity of Chinese provinces vs. (a) GDP, (b) the ratio of industrial output to GDP, (c) energy intensity of GDP and (d) energy intensity of total freight.
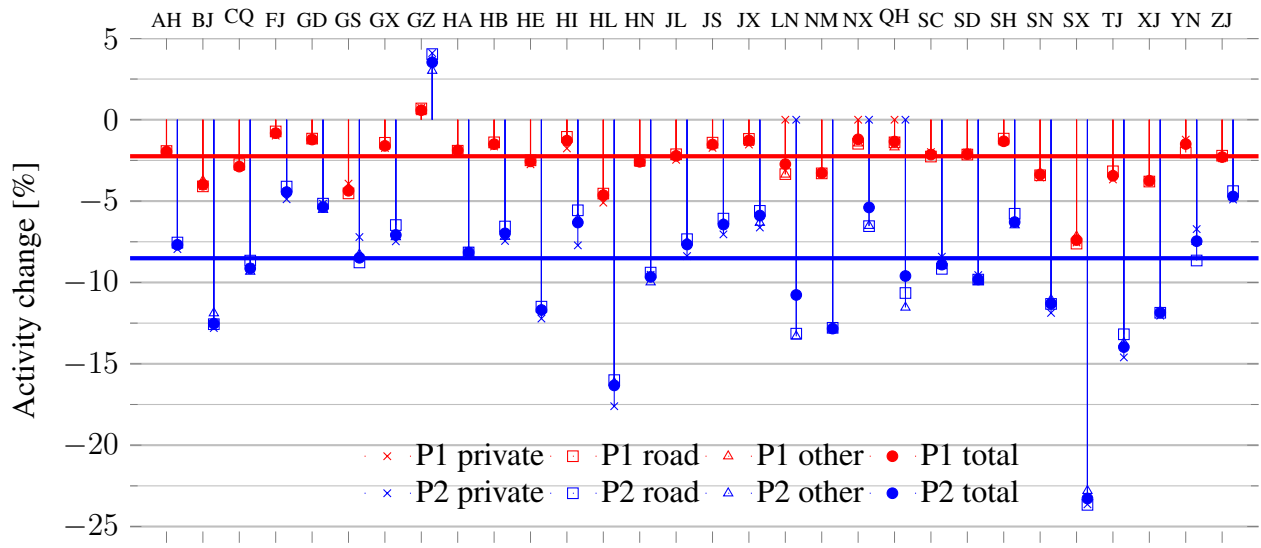
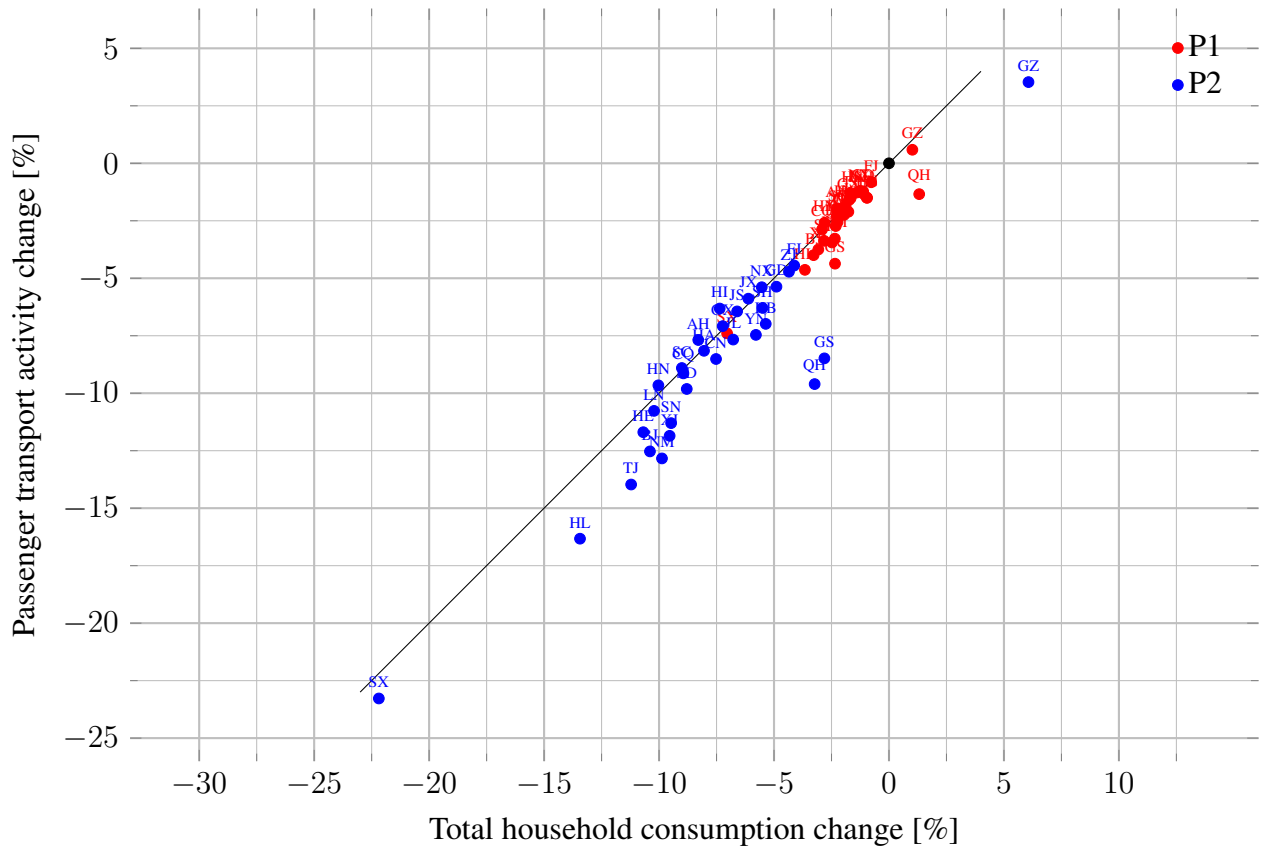**Figure 16.** Policy impact on passenger transport by mode and Chinese province.

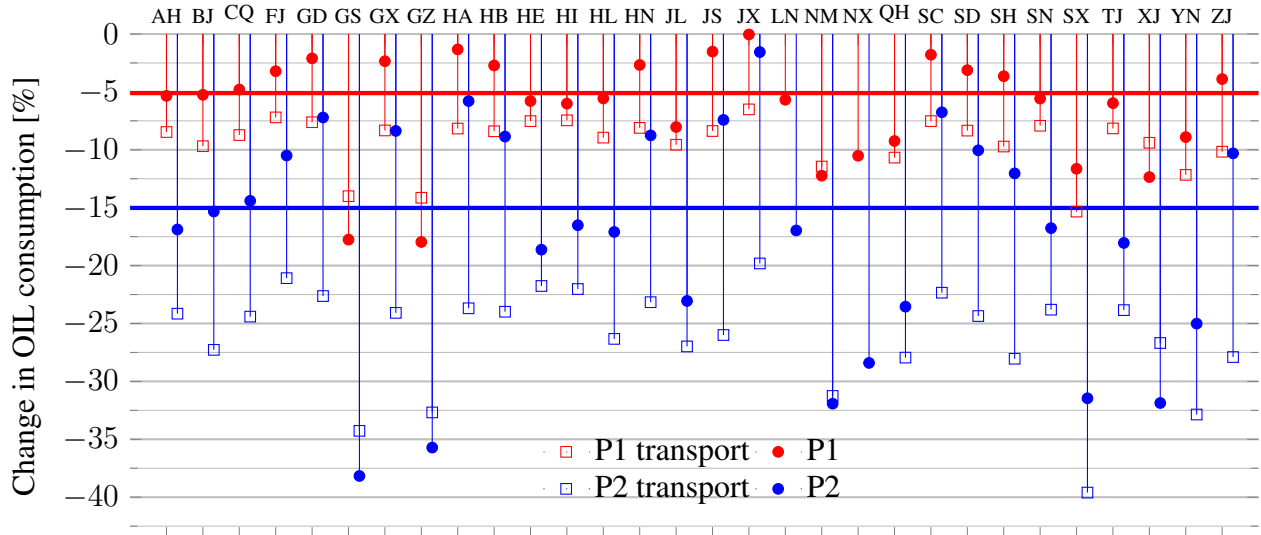**Figure 17.** Change in consumption versus change in passenger activity level.

20

Figure 18. Change in total refined oil use, Chinese provinces, with the aggregate change in the national total (solid lines).

demand for transport sector output; and improvements in emissions intensity of transport coming from substitution away from `OIL` to lower-intensity fuels (`GAS`), or away from energy- to non-energy inputs.

Figure 19 illustrates the relationship between freight and passenger transport systems impacts in individual provinces. We observe significant heterogeneity across provinces in terms of the absolute and relative impact on the transportation system, as well as whether freight or passenger travel are most affected. In many provinces, freight and passenger activity are fairly evenly affected (close to the 45-degree line of Figure 19) under Policy 1. Among those exhibiting uneven reductions in freight and passenger activity, some (e.g. Yunnan) see the effects become more even as the stringency of policy increases, while in others (e.g. Heilongjiang) the effect becomes more skewed. In a few provinces, effects on freight and passenger transport activity have opposite signs. In Guizhou passenger activity increases while freight activity decreases; in Fujian and Jiangxi, freight activity increases while passenger activity decreases.

The magnitude of freight sector impacts can also potentially be explained by whether the province is a supplier of raw materials (especially if energy-intensive) to other provinces, and if and this activity is large relative to total provincial GDP—the impact on freight could be more severe in Inner Mongolia, Gansu, Guizhou, and Shanxi, which are all in this category.

4. DISCUSSION & CONCLUSIONS

CGE models such as the C-REM assume reductions—to emissions intensity, in this case, but equivalently to energy intensity, total energy or total emissions—are taken starting from the most cost-effective opportunities. It may be difficult in practice to assess whether or where within the transport sector these opportunities lie, and then to incentivize actors to make them. The success of any transport-focused policy or economy-wide policy that includes the transport sector depends critically on how individual actors experience and respond to the incentives that policy
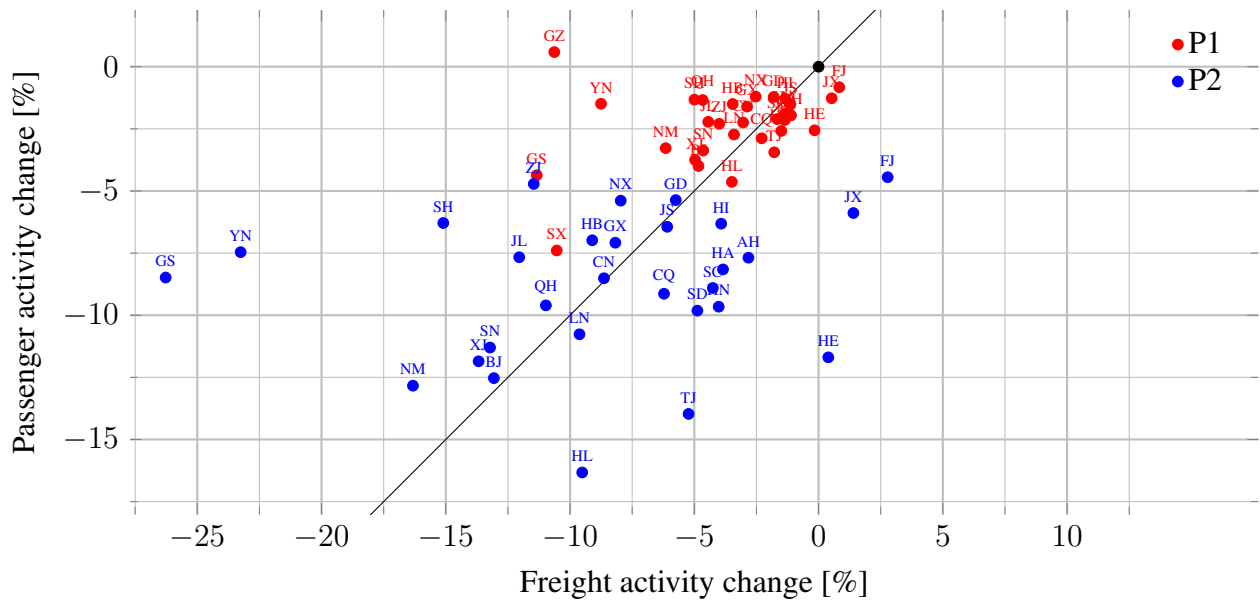
Figure 19. Policy impact in freight vs. passenger activity, by province.

creates.

Our work uses the same value of 0.2 for the elasticity of substitution between household vehicle transport and commercial passenger transport as in the MIT EPPA model (from which our household vehicle transport sector is derived). We also use a substitution elasticity of 0.2 between the commercial passenger modes, while we model a greater substitutability (elasticity of 1) between freight modes. These choices are somewhat reflected in the results. The sensitivity of outputs to changes in transport elasticities is an initial task for verification of our conclusions; better still would be values derived from empirical research specific to China.

The relatively large contribution of freight transport to emissions abatement suggests that it is important to include these modes in national carbon reduction efforts; so accounting for (and assessing reductions in) freight transport sector emissions will be important to national policy. Some regions—Europe, for instance—initially excluded transport and its opportunities for emissions abatement from trading systems, using the rationale that fuels were already heavily taxed, which resulted in a high implicit carbon price (Abrell, 2010). Refined oil taxes harmonized with an emissions pricing scheme may also be an option for China.

The results indicate the relative cost of improving energy intensity is higher in transport than in other sectors. These results are consistent with China's passenger transport system currently being relatively efficient per passenger-kilometre, in part because of the model split. Also, a reliance on smaller vehicles may allow China's fleet to be more fuel efficient on average than, for instance, that of the United States. However, as manufacturers bring to market more spacious, heavier, higher performance vehicles with more amenities and consumers develop tastes for these, it is uncertain how the future will evolve.

Regarding provincial impacts, we find ready explanations for many of the differences in impacts across modes and provinces, yet the identified drivers vary across provinces, sector uses,

and modes. The energy intensity of provincial GDP, industrial structure, present mode share and energy intensity of modes all modify policy impacts on freight transport activity. Further study is warranted on the intermediate demand for freight transport services, to identify whether the movement of certain freight goods (e.g., raw materials, including coal) responds more strongly to climate policy than others.

Road transport is more carbon-intensive at present, so we would expect any policy focused on carbon to reduce the road share. Purchased modes generally offer lower carbon intensity and mode shifting could reduce emissions per passenger-kilometre. Further research could quantify the magnitude of this effect in each province.

China's transport system, and its response to policy, is hardly uniform, reinforcing the lesson that treating the entire system as an undifferentiated whole leads to a "flaw of averages."[5] Regional analysis reveals relative winners and losers—sometimes both in one province. These results could inform the discussion between provincial and central government officials on the type, stringency, and allocation (if any) of policies on climate, energy, and particular transport technologies and modes.

4.1 Future Work

In addition to providing insights about different responses of transport in Chinese provinces to a national emissions intensity target, we have established a framework for planned further study of regional transport. The newly developed modeling capacity will allow future work to:

- represent existing policies which differ from province to province, or are piloted in some provinces before being adopted more widely;

- represent policies proposed or considered by individual provinces, or national policies which may have regionally heterogeneous impact; and

- incorporate improved understanding of the characteristics of regional transport systems.

The latter point may include improving calibration (with additional data sources, aggregation of bottom-up data, or survey-based information on—for instance—mobility habits and preferences of consumers), endogenous representation of phenomena such as congestion (as demonstrated by Conrad (1997) generally and Gorman (2008) for freight), or increasing the supply of non-road modes according to statistics on investment in urban and intercity rail.

Karplus, Paltsev, Babiker, Heywood, *et al.* (2012) describe a production function in which NEV technologies—including pure electric (EV), plug-in hybrid electric (PHEV), and compressed natural gas vehicles (CNGV)—provide household vehicle transport using different energy inputs, at different emissions intensities and costs. We included only an internal combustion vehicle (ICEV) technology, but adoption of NEVs in response to policy can be assessed by calibrating these as backstop alternatives to ICE technology.

Finally, in addition to GHGs, road vehicles and other energy inputs to transport are associated with emissions of precursor pollutants which contribute to the variable and occasionally

---

[5] For a detailed treatment of this term, see Neufville *et al.* (2011, Chapter 2).

Table 4. Transport sector policies for future study.

	Policy	C-REM Sectors(s)
1	Tailpipe emission standards/fuel quality standards	HVT
2	New vehicle fuel economy (CO_2 emissions) standards	HVT, FR, and/or PR
3	Alternative fuel vehicle subsidies	HVT, FR, and/or PR
	A. Pure electric (EV) and hybrid electric (HEV) vehicles	"
	B. Methanol vehicles	"
	C. Compressed natural gas (CNG) vehicles	"
4	Vehicle ownership or usage taxes	HVT and/or PR
5	National cap-and-trade system focused on CO_2 emissions	(all)
6	Incentives to retire high emitting vehicles early	HVT, FR, and/or PR

dangerously poor air quality in some of China's cities. Each categories of transport sources allows different methods of pollution control, with distinct costs per unit of abatement. Assigning emissions factors of these pollutants to individual transport modes will yield total emissions of precursors pollutants by province, a critical step in assessing whether policies such as those in **Table 4** can improve air quality—and if so, where.

4.2 Summary

Motivated by rapid growth, a variety of national and regional policies, and hetereogeneity in regional characteristics of China's transport system (Section 1, Section 2.3), we added detail in both household vehicle transport and commercial freight and passenger transport to the C-REM CGE model of China's provinces (Section 2). To investigate the variation of responses across provinces and sectors (including the new transport sectors), we imposed national policies on the CO_2-emissions intensity of GDP (Section 3). We found that percentage changes in provincial freight activity related strongly to the demand for the freight transport service, which decreased most in provinces with high energy (and thus emissions) intensity of production and low-cost opportunities for emissions abatement. While passenger modes decreased in both activity and energy intensity under policy, their small share of transport energy demand meant that their contributions to transformation of the overall transport energy system were modest. While our work here focused on the impacts of national and economy-wide policy, we outlined how the additional transport detail will allow further study of China's existing transport policies, some of which are narrowly targeted at particular provinces and/or transport subsectors (Sections 1.1 and 4.1).

ACKNOWLEDGEMENTS

5. REFERENCES

Abrell, J., 2010. "Regulating CO_2 emissions of transportation in Europe: A CGE-analysis using market-based instruments." In: *Transportation Research Part D: Transport and Environment* 15.4, p. 235. DOI: 10.1016/j.trd.2010.02.002.

Cai, B., X. Feng, and X. Zhen, eds., 2012. *Transport Carbon Dioxide Emissions and Low Carbon Development*. Low Carbon City Series. Beijing, China: Chemical Industry Press.

Caixiong, Z., 2012. *"Guangzhou to limit number of car plates," China Daily, 11 July 2012*. Accessed 01 August 2012. URL: http://www.chinadaily.com.cn/china/2012-07/11/content_15567125.htm.

Campos, J. and G. de Rus, 2009. "Some stylized facts about high-speed rail: A review of HSR experiences around the world." In: *Transport Policy* 16.1, pp. 19–28. DOI: 10.1016/j.tranpol.2009.02.008.

Cherry, C. R., J. X. Weinert, and X. Yang, 2009. "Comparative environmental impacts of electric bikes in China." In: *Transportation Research Part D: Transport and Environment* 14, pp. 281–290. DOI: 10.1016/j.trd.2008.11.003.

Chien, S.-S. and B. Ho, 2011. "Globalization and the local government learning process in post-Mao China: a transnational perspective." In: *Global Networks* 11.3, pp. 315–333. DOI: 10.1111/j.1471-0374.2011.00328.x.

China Communications & Transportation Association, ed., 2008. *Year Book of China Transportation & Communications*. 2008. Beijing, China: Year Book House of China Transportation & Communications.

– ed., 2009. *Year Book of China Transportation & Communications*. 2009. Beijing, China: Year Book House of China Transportation & Communications.

China State Information Council, ed., 2011. *China Input-Output Tables*. 2007. Beijing, China: China Statistics Press. ISBN: 9787503763755.

Conrad, K., 1997. "Traffic, transportation, infrastructure and externalities." In: *The Annals of Regional Science* 31.4, pp. 369–389. DOI: 10.1007/s001680050054.

Daojiong, Z., 2006. "China's energy security: Domestic and international issues." In: *Survival* 48.1, pp. 179–190. DOI: 10.1080/00396330600594322.

de Jong, M. *et al.*, 2010. "Introducing public–private partnerships for metropolitan subways in China: what is the evidence?" In: *Journal of Transport Geography* 18.2, pp. 301–313. DOI: 10.1016/j.jtrangeo.2009.06.013.

Euromonitor International, 2011. *Passport Global Market Information Database*. Statistics retrieved 16 October 2011.

Girod, B., D. P. van Vuuren, and S. Deetman, 2012. "Global travel within the 2°C climate target." In: *Energy Policy* 45, pp. 152–166. DOI: 10.1016/j.enpol.2012.02.008.

Gong, H., M. Q. Wang, and H. Wang, 2012. "New energy vehicles in China: policies, demonstration, and progress." In: *Mitigation and Adaptation Strategies for Global Change* 18.2, pp. 207–228. DOI: 10.1007/s11027-012-9358-6.

Gorman, M. F., 2008. "Evaluating the public investment mix in US freight transportation infrastructure." In: *Transportation Research Part A: Policy and Practice* 42.1, pp. 1–14. DOI: 10.1016/j.tra.2007.06.012.

Guan, D. *et al.*, 2012. "The gigatonne gap in China's carbon dioxide inventories." In: *Nature Climate Change* 2, pp. 672–675. DOI: 10.1038/nclimate1560.

Hao, H., H. Wang, and M. Ouyang, 2011. "Comparison of policies on vehicle ownership and use between Beijing and Shanghai and their impacts on fuel consumption by passenger vehicles." In: *Energy Policy* 39.2, pp. 1016–1021. DOI: 10.1016/j.enpol.2010.11.039.

Holz, C. A., 2004. "China's Statistical System in Transition: Challenges, Data Problems, and Institutional Innovations." In: *Review of Income and Wealth* 50.3, pp. 381–409. DOI: 10.1111/j.0034-6586.2004.00131.x.

Hu, X. *et al.*, 2010. "Energy for sustainable road transportation in China: Challenges, initiatives and policy implications." In: *Energy*, pp. 4289–4301. DOI: 10.1016/j.energy.2009.05.024.

Huang, C. *et al.*, 2005. "Urban travel modal split and its impact on energy and environment." In: *Journal of Highway Transport Res Development* 22.11. (in Chinese), pp. 163–166.

Huo, H. *et al.*, 2012. "Vehicle-use intensity in China: Current status and future trend." In: *Energy Policy* 43, pp. 6–16. DOI: 10.1016/j.enpol.2011.09.019.

International Energy Agency, 2010. *World Energy Balances 1970-2009*. Accessed October, 2011. DOI: 10.1787/data-00512-en.

International Road Federation, 2010. *World Road Statistics 2010 and electronic files*.

Karplus, V. J., S. Paltsev, M. H. Babiker, J. B. Heywood, *et al.*, 2012. *Applying Engineering and Fleet Detail to Represent Passenger Vehicle Transport in a Computable General Equilibrium Model*. Tech. rep. 216. Cambridge, MA, USA: MIT Joint Program on the Science & Policy of Global Change. HDL: 1721.1/70564.

Karplus, V. J., S. Paltsev, M. H. Babiker, and J. M. Reilly, 2013. "Applying engineering and fleet detail to represent passenger vehicle transport in a computable general equilibrium model." In: *Economic Modelling* 30, pp. 295–305. DOI: 10.1016/j.econmod.2012.08.019.

Kishimoto, P. N., 2012. "Applying Advanced Uncertainty Methods to Improve Forecasts of Vehicle Ownership and Passenger Travel in China." In: *31st USAEE/IAEE North American Conference*. Austin, TX, USA.

Kishimoto, P. N., S. Paltsev, and V. J. Karplus, 2012. *The Future Energy and GHG Emissions Impact of Alternative Personal Transportation Pathways in China*. Cambridge, MA, USA: MIT Joint Program on the Science & Policy of Global Change. HDL: 1721.1/73607.

Li, J. and J. Y. Cheng, 2012. "4. Cadre Performance Appraisal and Fabrication of Achievement in Chinese Officialdom." In: *China: A New Stage of Development for an Emerging Superpower*. Ed. by J. Y. Cheng. Kowloon, Hong Kong, China: City University of Hong Kong Press, pp. 117–148. ISBN: 9789629371975. URL: http://books.google.com/books?id=iFSwu2UcvtEC.

Nam, K.-M., 2011. "Learning through the international joint venture: lessons from the experience of China's automotive sector." In: *Industrial and Corporate Change* 20.3, pp. 855–902. DOI: 10.1093/icc/dtr015.

Narayanan G., B., A. Aguiar, and R. MacDougall, 2012. *Global Trade, Assistance, and Production: The GTAP 8 Data Base*. Tech. rep. Available online at: https://www.gtap.agecon.purdue.edu/databases/v8/. West Lafayette, Indiana, USA: Center for Global Trade Analysis, Purdue University.

National Bureau of Statistics of China, ed., 2008. *China Statistical Yearbook*. 2008. Beijing, China: China Statistics Press.

Neufville, R. de and S. Scholtes, 2011. *Flexibility in Engineering Design*. Engineering Systems. Cambridge, Massachsetts: The MIT Press.

Oliver, H. H. *et al.*, 2009. "China's fuel economy standards for passenger vehicles: Rationale, policy process, and impacts." In: *Energy Policy* 37.11, pp. 4720–4729. DOI: 10.1016/j.enpol.2009.06.026.

Ou, X., X. Yan, and X. Zhang, 2010. "Using coal for transportation in China: Life cycle GHG of coal-based fuel and electric vehicle, and policy implications." In: *International Journal of Greenhouse Gas Control* 4.5, pp. 878–887. DOI: 10.1016/j.ijggc.2010.04.018.

Paltsev, S. *et al.*, 2005. *The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4*. Tech. rep. 125. Cambridge, MA: MIT Joint Program on the Science and Policy of Global Change. HDL: 1721.1/29790.

Peng, Z.-R., 2004. *Urban Transportation Strategies in Chinese Cities and Their Impacts on the Urban Poor*. Comparative Urban Studies Program Report. Washington, DC, USA: Woodrow Wilson International Center for Scholars.

Qi, T. *et al.*, 2012. *Will Economic Restructuring in China Reduce Trade-Embodied CO* Emissions?* Tech. rep. 232. Cambridge, MA, USA: MIT Joint Program on the Science and Policy of Global Change. HDL: 1721.1/73903.

Rausch, S. *et al.*, 2010. "Distributional Implications of Alternative U.S. Greenhouse Gas Control Measures." In: *The B.E. Journal of Economic Analysis & Policy* 10.2. Also published as NBER Working Paper No. 16053. DOI: 10.2202/1935-1682.2537.

Schäfer, A., 1998. "The global demand for motorized mobility." In: *Transportation Research Part A: Policy and Practice* 32.6, pp. 455–477. DOI: 10.1016/S0965-8564(98)00004-4.

Steinfeld, E. S., 2008. "Energy Policy." In: *China Urbanizes: Consequences, Strategies, and Policies*. Ed. by S. Yusuf and A. Saich. Directions in Development: Countries and Regions. Washington, DC, USA: 6: The World Bank. Chap. 6, pp. 125–156. ISBN: 9780821372111. DOI: 10.1596/978-0-8213-7211-1.

Suen, A., 2012. *Personal correspondence*. MAP Sustainable Energy Fellow, National Resources Defence Council, Beijing, China.

Sun, Y. *et al.*, 2004. "The air-borne particulate pollution in Beijing—concentration, composition, distribution and sources." In: *Atmospheric Environment* 38.35, pp. 5991–6004. DOI: 10.1016/j.atmosenv.2004.07.009.

UN FCCC Secretariat, 2011. *Compilation of information on nationally appropriate mitigation actions to be implemented by Parties not included in Annex I to the Convention*. FCCC/AWGLCA/2011/INF.1. Geneva, Switzerland: United Nations, Framework Convention on Climate Change, Ad Hoc

Working Group on Long-term Cooperative Action under the Convention. URL: http://unfccc.int/documentation/documents/advanced%5C_search/items/6911.php?priref=600006178.

Wang, M. *et al.*, 2006. *Projection of Chinese Motor Vehicle Growth, Oil Demand and CO_2 Emissions Through 2050*. Report ANL/ESD/06-6. Argonne, IL, USA: Argonne National Laboratory. URL: https://greet.es.anl.gov/publication-rwdz78ca.

Wang, Y. *et al.*, 2011. "Investment and Financing Mechanism of Public Transport in China." In: *2011 International Conference on Management and Service Science*. Wuhan, China, pp. 1–4. DOI: 10.1109/ICMSS.2011.5998557.

Weinert, J., C. Ma, and C. Cherry, 2007. "The transition to electric bikes in China: history and key reasons for rapid growth." In: *Transportation* 34.3, pp. 301–318. DOI: 10.1007/s11116-007-9118-8.

Weinert, J., J. Ogden, *et al.*, 2008. "The future of electric two-wheelers and electric vehicles in China." In: *Energy Policy* 36.7, pp. 2544–2555. DOI: 10.1016/j.enpol.2008.03.008.

Xin, Z., 2012. *"New fuel standards to cut pollution in city," China Daily, 18 May 2012*. Accessed 01 August 2012. URL: http://www.chinadaily.com.cn/china/2012-05/18/content_15325468.htm.

Xinhua News Agency, 2012. *"China's imported oil dependence continues to rise", 10 May 2012*. URL: http://news.xinhuanet.com/english/china/2012-05/10/c_131580559.htm.

Yan, X. and R. J. Crookes, 2010. "Energy demand and emissions from road transportation vehicles in China." In: *Progress in Energy and Combustion Science* 36, pp. 651–676. DOI: 10.1016/j.pecs.2010.02.003.

Yin, J. *et al.*, 2011. "Monitoring urban expansion and land use/land cover changes of Shanghai metropolitan area during the transitional economy (1979–2009) in China." In: *Environmental Monitoring and Assessment* 177, pp. 609–621. DOI: 10.1007/s10661-010-1660-8.

Zhang, D. *et al.*, 2012. *Quantifying Regional Economic Impacts of CO_2 Intensity Targets in China*. Tech. rep. 230. Cambridge, MA, USA: MIT Joint Program on the Science & Policy of Global Change. HDL: 1721.1/73005.

APPENDIX A: C-REM Regions and Calibration Data
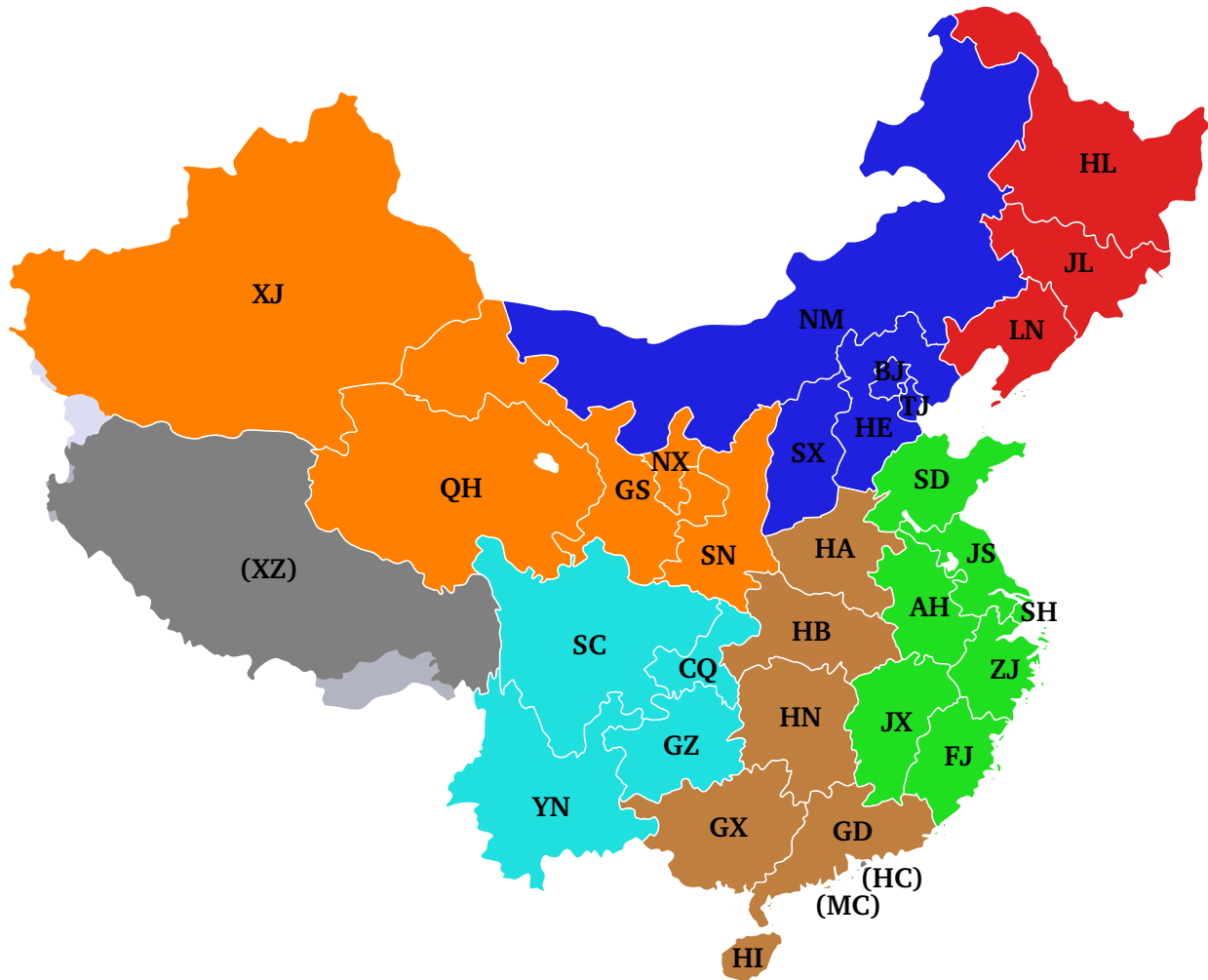
Code	Name	Code	Name	Code	Name
AH	安徽 Anhui	HE	河北 Hebei	QH	青海 Qinghai
BJ	北京 Beijing	HI	海南 Hainan	SC	四川 Sichuan
CQ	重庆 Chongqing	HL	黑龙江 Heilongjiang	SD	山东 Shandong
FJ	福建 Fujian	HN	湖南 Hunan	SH	上海 Shanghai
GD	广东 Guangdong	JL	吉林 Jilin	SN	陕西 Shaanxi
GS	甘肃 Gansu	JS	江苏 Jiangsu	SX	山西 Shanxi
GX	广西 Guangxi	JX	江西 Jiangxi	TJ	天津 Tianjin
GZ	贵州 Guizhou	LN	辽宁 Liaoning	XJ	新疆 Xinjiang
HA	河南 Henan	NM	内蒙古 Inner Mongolia	YN	云南 Yunnan
HB	湖北 Hubei	NX	宁夏 Ningxia	ZJ	浙江 Zhejiang

Figure A1. Provinces of China, with regional colouring scheme used in Figure 1. Hong Kong (HK), Macau (MC) and Xizhang (Tibet, XZ) are not included in the C-REM.

Table A1. Energy intensity by mode from literature, with values used in this study in bold. (1) Citing the China Ministry of Railways Statistical Bulletin for 2008, a value of 5.78 t coal equivalent per 10^5t·km. (2) Citing Cherry *et al.* (2009), for bus. (3) For heavy-duty gasoline or diesel bus in Shanghai, (4) for light-duty bus, (5) for liquid propane gas (LPG) taxi, all citing Huang *et al.* (2005). (6) This official statistical publication reports an aggregate indicator of air traffic in t·km which includes pass.·km converted at the given rate.

	Mode			
Source	**Air**	**Road**	**Rail**	**Water**
Freight [MJ/t·km]				
Cai *et al.* (2012)	**9.01**	**1.7**	**0.1694**[1]	0.219
Ou *et al.* (2010)	—	1.362	0.24	**0.148**
Passenger [MJ/pass.·km]				
Cai *et al.* (2012)	—	—	—	$\frac{1}{3}\frac{\text{t·km}}{\text{pass.·km}}$=**0.073**
Yan & Crookes(2010)	—	0.31–0.94[2]	—	—
		0.53[3]		
		1.658[4]		
		3.411[5]		
Girod *et al.* (2012)	—	**0.9**	**1.04**	—
CCTA (2008; 2009)	$0.09\frac{\text{t·km}}{\text{pass.·km}}$=**0.81**[6]	—	—	—

REPORT SERIES of the MIT Joint Program on the Science and Policy of Global Change

FOR THE COMPLETE LIST OF JOINT PROGRAM REPORTS: http://globalchange.mit.edu/pubs/all-reports.php

Contact the Joint Program Office to request a copy. The Report Series is distributed at no charge.