

**Passenger Transport in China Under Climate Constraints:
General Equilibrium Analysis, Uncertainty, and Policy**

by

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B.A.Sc. Engineering Science, University of Toronto (2008)

Submitted to the Engineering Systems Division
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Abstract

Vehicle sales and road travel volume in China have grown rapidly in recent years, and with them energy demand, greenhouse gas emissions and local air pollution. Aviation and rail travel have also grown, while ceding a large share to private vehicles. What path will household transport demand in China take in the future? How might it interact with policies which limit greenhouse gases, and what are the implications for energy use, the environment and the economy?

To contribute policy insights and a foundation for future study in this area, I undertake a new calibration of the Chinese household transport sector in the MIT Emissions Prediction & Policy Analysis (EPPA) computable general equilibrium (CGE) model, implementing income elasticities of demand for vehicle travel and vehicle stock growth based on historical data. To bracket uncertainty in the literature, I impose three scenarios of future growth in demand for purchased (air, rail and marine) and vehicle modes. These are explored under a no-policy baseline, a climate-stabilization policy, and with a policy that extends the emissions-intensity goal of China's Twelfth Five-Year Plan—both policies are modelled as caps creating prices on carbon.

Examining the results, I find that trends in growth are only modestly affected by policy continuing present energy-intensity goals, with small decreases in travel activity and energy intensity of vehicles combining for a reduction in refined oil use; such a policy has modest cost and affects household transport less than other sectors. In contrast, my results show that a stringent emissions cap has large impacts on vehicle efficiency, limits vehicle ownership and general travel activity levels. Compared to the no-policy baseline, a smaller vehicle fleet (250 million total, or 200 per 1000 capita). Sixteen percent of the fleet is new energy vehicles (plug-in hybrid-electrics), while total refined oil use increases by 2050 to nearly three times its 2010 level. However, these effects come with a reduction in total primary energy as the policy is introduced, and large costs economy-wide. Chinese national and municipal policies include objectives of promoting vehicle ownership and mobility on the one hand, and of reducing dependence on carbon-intensive refined oil on the other. My findings illustrate that

these goals are at odds, and offer inputs to policy design related to vehicle sales, public transit, congestion, pollution and energy security.

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Section 4.1 began as work for Stephen Hammer's course in *Energy Policy for a Sustainable Future*, and benefits from candid remarks on the political economy of energy and transport in China, made by colleagues from Tsinghua University, as well as stakeholders in the Tsinghua-MIT China Energy & Climate Project (CECP), during the CECP Annual Meeting in Beijing, 17-18 May 2012, and subsequent meetings. I identify these in the bibliography but do not attribute individual comments.

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Nomenclature

- N*-FYP *N*th Five-Year Plan
- AEEI Autonomous energy efficiency improvement
- CES Constant elasticity of substitution
- CGE Computable general equilibrium
- EPPA MIT Emissions Prediction & Policy Analysis model
- FES Fuel economy standards
- GAMS General Algebraic Modelling System
- GHG Greenhouse gases
- HTRN Household transport
- IJV International joint venture
- MPSGE Mathematical Programming System for General Equilibrium Analysis
- NEV New Energy Vehicle
- PDT Passenger distance travelled \equiv VDT \times vehicle occupancy
- PTOI Industrial (OTHR sector) input to own-supplied transport representing vehicle powertrain capital
- SOE State-owned enterprise
- TOI Industrial (OTHR sector) input to own-supplied transport, representing non-powertrain vehicle capital
- TRO Refined oil (ROIL sector) input to own-supplied transport
- TSE Services (SERV sector) input to own-supplied transport
- VDT Vehicle distance travelled

Chapter 1

Motivation

1.1 Introduction

Transportation is an important aspect of development. Human mobility brings access to employment and income, goods and services, and the pleasure of travel itself; cargo transport allows valued resources and goods to reach people where they live and work. When developing nations and their citizens pursue economic growth and transformation as a way of improving quality of life, the past suggests that transport growth is inevitable (Schäfer and Victor, 2000; Dargay et al., 2007).

Among rapid developing nations, the BRIC countries—Brazil, Russia, India and China—are often singled out for the weighty combination of their populations and rates of growth; and China is foremost in both. China’s government has aggressively promoted economic growth, and in turn, Chinese citizens have spent their rising incomes and wealth on travel, resulting in growth in travel volume, energy use, and emissions; and changes in the modes share for different means of transport which have been characterized as *faster, sooner and more simultaneously* than the historical pattern in the United States (Marcotullio et al., 2005).

After a period of rapid expansion in all areas, China faces difficult policy choices. It is called to participate in global efforts to meet global greenhouse gas concentration targets, which are unlikely to proceed or succeed without its participation (Paltsev et al., 2012). In response, its government has focused on the language in the original Kyoto

Protocol that allows for “common but differentiated responsibilities”—expressing its duty to continue improving quality of life for its citizens, even if this means an increase in its total greenhouse gas emissions. And even were it not concerned with the effects of climate change, the central government indirectly acknowledges that the rate of expansion—the “development of China’s advanced productive forces” which supports the “fundamental interests of the overwhelming majority of the people” (Jiang, 2000)—is economically unsustainable in its present form. Discussion of *economic rebalancing* signals intent to actively manage an increase in services as a fraction of GDP, while relying less on exports than on developing domestic markets for consumer goods—including household vehicles—to support economic growth. The Communist Party of China’s continued pursuit of a harmonious (和谐社会, *héxié shèhuì*) and basically well-off (小康, *xiaokang*) society depends on the success of this transition.

1.2 Household transport policy: challenges and evidence

China has achieved unprecedented rates of economic growth over the past 20 to 30 years. However, while aiming for a high level of income, it is also attempting to mitigate or bypass the higher environmental impacts temporarily experienced by developing nations during their growth (Geng and Doberstein, 2008). In any such transition the sequencing of events has a role in shaping their outcomes. This feature appears in the transport sector—high speed rail and air travel infrastructure are being built while auto ownership remains at a fraction of the current levels in the United States, Western Europe or Japan (OECD, 2012; Campos and de Rus, 2009). China differs from the sequence in those countries where automobiles were available before these higher-speed technologies were developed (Schäfer and Victor, 2000). Figure 1-1 shows both that wealthier provinces are more highly motorized, but also that strong differences are possible within the country and may be attributed at least in part to the effect of policy measures—for instance in Shanghai, aimed at mitigating environmental impacts, that have caused a different growth path than in Beijing. The switch from low-speed modes—walking, bicycles, buses—to private transport—motorized scooters, motorcy-

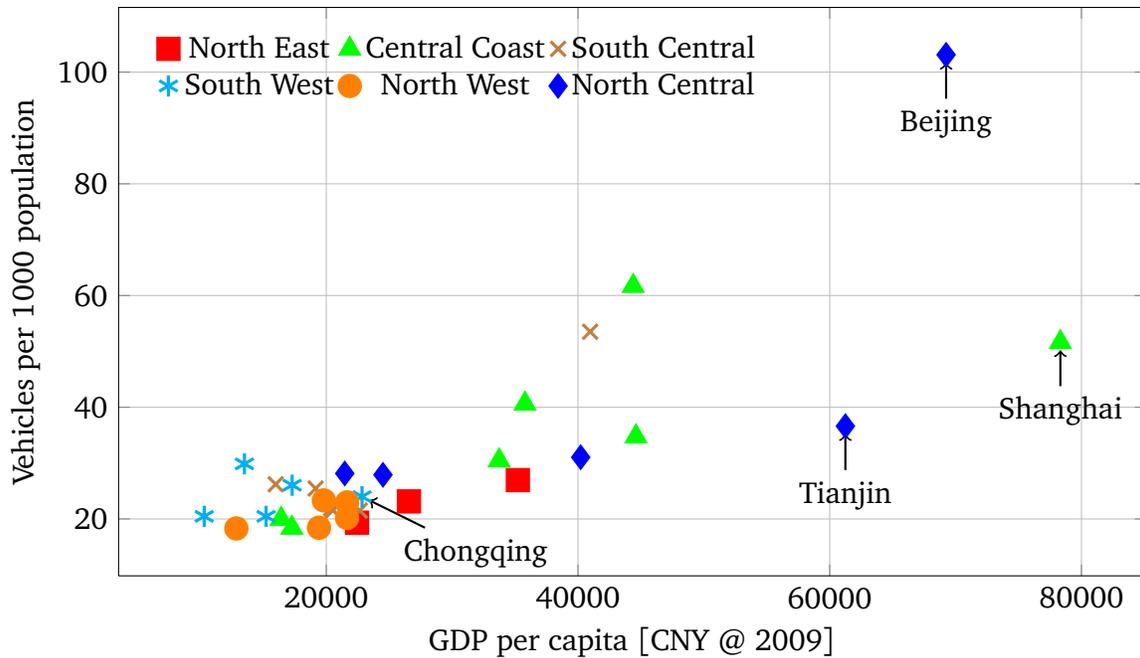


Figure 1-1: Static income–ownership relationship for Chinese provinces as of 2009 (National Bureau of Statistics of China, 2011). Each data point corresponds to a Chinese province, which are grouped into six regions. The four direct-controlled municipalities are labelled; see Appendix B for their locations.

cles, passenger cars, light trucks and other light-duty vehicles—that accompanies increasing household income (Schäfer et al., 2009) is occurring at a pace concomitant with general economic growth. As a result, China has become the world’s largest market for new, light-duty vehicles (Wang et al., 2011), and its refined oil demand has outstripped domestic supply. In 2011, China imported 56.7 percent of the oil it consumed, a fraction that has raised concerns about security of supply and vulnerability to rapid changes in prices (Xinhua News Agency, 2012).¹

Rapidly growing energy use and emissions from Chinese transport contribute to problems of global environmental externalities, wherein unpriced, common goods (in this case, sources of limited resources and sinks for greenhouse gases) are overused;

¹These national concerns, referred to hereinafter as "energy security," bear resemblance to the concern of global sustainability (Kruyt et al., 2009). Security of supply concerns encompass the negative consequences, such as price shocks, of high demand when supply is beyond the direct control of national governments. But the extent and accessibility of global fossil fuel resources are beyond the control of any government, so the interaction between high demand and total supply raises similar problems, while not allowing some traditional, national energy security responses, such as foreign policy.

but in major urban centres they are also giving rise to local externalities—traffic congestion on the “concrete commons” (Coughlin, 1994) and local air pollution (Saikawa et al., 2011)—which are familiar in developed countries. However, where Chinese policy is addressing these issues, it does so within a form of government and in transport markets which differ from to the well-studied situations in advanced industrialized countries—in particular, the United States, Western Europe and Japan. Due to Chinese governments’ capacity to act, including diminishing yet still significant willingness and ability to employ direct management, and the relationship between municipal and central government officials, policymakers are employing a variety of measures influenced by foreign examples and aimed at a variety of goals (Chien and Ho, 2011; Brown and Sovacool, 2011).

Given high uncertainty, there is a recognized need for continual improvement in projections of transport energy use and vehicle ownership as an input to policy. Global, computable general equilibrium modelling is a method which can be used to simulate these trends while including the effects of growth in other sectors, and can also be used to study limits on greenhouse gas emissions which may affect household transport projections through prices.

1.3 Contribution and organization

In this thesis I contribute to the understanding of the household transport policy challenges and options facing China, and in particular their interaction with efforts to address climate change through carbon dioxide (CO₂) emissions, and the combined energy and economic effects of both. I do so with particular attention to alternative futures in the evolution of demand for two types of household transport: *own-supplied* or private vehicle transport, in which households buy and use light duty vehicles to travel; and *purchased* transport, in which travel on buses, subways, railways, marine vessels and aircraft is paid for directly. I apply a general equilibrium model that includes detail on the Chinese economy to study transportation developments there, and their implications for CO₂ emissions.

In **Chapter 2**, I adapt an existing CGE model to better represent increases in demand for the two types of transport under China's rapid economic growth by including price effects and feedbacks possible in a model of the global economy. The model calibration is updated in response to data availability challenges and the structure of the Chinese vehicle fleet. By modelling sectoral growth which occurs much more rapidly than general economic growth, observations up to the present are matched, and I develop three scenarios of future demand for transport and the own-supplied portion. I develop two types of example policy in order to study their impact on energy use, greenhouse gas emissions and transport demand.

Chapter 3 reports the results of these simulations. I discuss effects on the stock of private vehicles with comparison to existing, non-CGE projections; on absolute demand for refined oil and primary energy and energy- and emissions intensities of transport; and finally the evolution of household budgets and general economic welfare with and without policy.

In **Chapter 4**, I consider the context and objectives of current national- and municipal-level policies focused on household and personal transport, and the dynamics between these, in view of the findings from Chapter 3. The policy implications of future transport demand and its interaction with types of climate policy are discussed, followed by a statement of some worthwhile extensions and a summary of the work.

Chapter 2

General equilibrium modelling of household transport

General equilibrium modelling, when compared to econometrics and other sector-specific approaches used to make projections of passenger travel in China, has the advantage of representing the entire economy. One disadvantage of a “top-down” approach is that sectoral detail may suffer. I make use of an existing computable general equilibrium (CGE) model, the MIT Emissions Prediction & Policy Analysis (EPPA) model, version 5, and add more realistic detail in China’s passenger transportation sector.

The purpose is threefold: first, to better represent the relationship of transport demand and associated energy use with growth of the economy in a rapidly developing country like China, by doing so within a CGE framework that includes potentially crucial feedback and interactions; second, to study how climate policies could affect decisions made by households to undertake transport activities which consume energy and emit greenhouse gases differently, and finally to examine these two types of responses in combination.

A description of the EPPA model is provided in Section 2.1. In Section 2.2 the model is updated to match data through the present for Chinese household transport in terms of sector inputs and rates of growth. Three scenarios of future demand and three climate policies are developed in Section 2.3; full results follow in Chapter 3.

2.1 The MIT Emissions Prediction & Policy Analysis (EPPA) Model

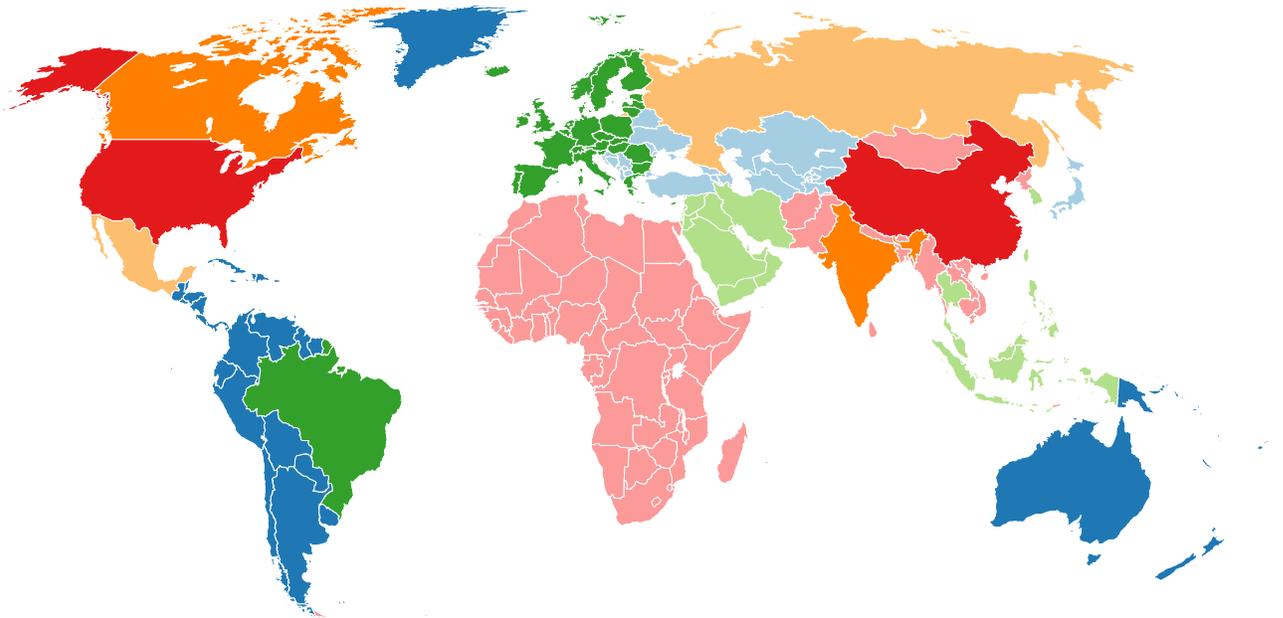
EPPA is a recursive-dynamic, multisector, multiregion computable general equilibrium model of the world economy. Paltsev et al. (2005) give extensive detail on the previous version, but because of changes in the updating of EPPA4 to EPPA5, and because the features and structure of the model are consequential in this analysis, a thorough description follows. To enable a variety of energy, climate and environmental policy studies, the economic accounts of EPPA disaggregate electricity generation, transport and other energy-intensive sectors; include representations of current, advanced and backstop technologies; and are supplemented with extensive physical accounts and flows tied to energy-consuming and emissions-generating activities. In particular, these include all six Kyoto Protocol greenhouse gases,¹ which may be treated separately or combined once converted to CO₂ equivalents according to their global warming potential, and also local pollutants² responsible for air quality issues, human health impacts, and other effects.

Sixteen regions correspond to either individual countries or groups of countries, with EPPA5 using the regional aggregation shown in Figure 2-1. Within each region, households provide services to production sectors using their endowments of labour, capital and resources. In return, they receive income payments which are used to purchase the goods and services produced. Fourteen sectors are currently represented as shown in Table 2-1. Trade flows between regions are represented under an Armington assumption, wherein imported goods are imperfect substitutes for domestic goods.

For projections, EPPA contains information on stocks of resources, with prices related to the marginal extraction costs. Population data from the United Nations' *World Population Prospects* (UN Population Division, 2010) is used to model growth in the labour endowment; labour productivity also increases with time. An autonomous en-

¹Carbon dioxide, CO₂; methane, CH₄; nitrous oxide, N₂O; hydrofluorocarbons, HFCs; perfluorocarbons, PFCs; and sulphur hexafluoride, SF₆.

²Including sulfur dioxide, SO₂; nitrogen oxides, NO_x; black carbon, BC; organic carbon, OC; ammonia, NH₃; carbon monoxide, CO; and non-methane volatile organic compounds, VOCs.



Code	Region	Code	Region
USA	United States	ASI	East Asia
CAN	Canada	CHN	China
MEX	Mexico	IND	India
JPN	Japan	BRA	Brazil
ANZ	Australia & New Zealand	AFR	Africa
EUR	Europe	MES	Middle East
ROE	Eastern Europe	LAM	Latin America
RUS	Russia-plus	REA	Rest of Asia

Figure 2-1: Map of EPPA regions.

Label	Description	Label	Description
CROP	Crops	GAS	Gas
LIVE	Livestock	ELEC	Electricity
FORS	Forestry	EINT	Energy-intensive industries
FOOD	Food products	OTHR	Other industries
COAL	Coal	SERV	Services
OIL	(Crude) Oil	TRAN	Transport
ROIL	Refined oil	CGD	Savings

Table 2-1: EPPA5 sectors.

ergy efficiency improvement (AEEI) in production structures represents trends unrelated to prices in the development and application of efficiency-increasing technologies, and other non-price effects which reduce the quantity of energy used to produce a unit of output. The initial period in EPPA5 is 2004, which matches the year of the GTAP7 data base which supplies the input-output tables used to generate the social accounting matrix (Narayanan and Walmsley, 2008). The model subsequently solves in 2005, and thereafter every five years until 2100, although in this work my focus is through 2050.

Capital in EPPA is vintaged, with some being retired in each period and replaced with new capital of similar type but greater efficiency, or of an alternate type. For most sectors, including electricity generation, there are five vintages of capital representing stock that is 5, 10, 15 and 20 years old, respectively. Under price pressure to alter production technology employed, for example as a result of climate policy, vintaging has the effect of limiting the rate of turnover of old stock (Paltsev et al., 2005).

EPPA is implemented in the GAMS/MPSGE software, a general-equilibrium modelling subsystem to the mathematical programming language GAMS (Rutherford, 1999). MPSGE transforms the model description into a mixed-complementarity problem which is solved as an optimization problem. The solution maximizes household utility and ensures market clearance, zero profit and income balance, the conditions for general equilibrium. The preferences of households over different types of consumption are benchmarked using share and price information in the base year, and are supplemented with outside information and estimates of long-run income elasticities and substitution elasticities of demand.

2.1.1 Household transport

To enable detailed, technology-rich study of household transport, Paltsev et al. (2004); Karplus (2011); Karplus et al. (2012b) introduced a set of enhancements to EPPA5 referred to collectively as EPPA-HTRN (for household transport), but now part of the standard configuration of the model. The transport component of household consumption

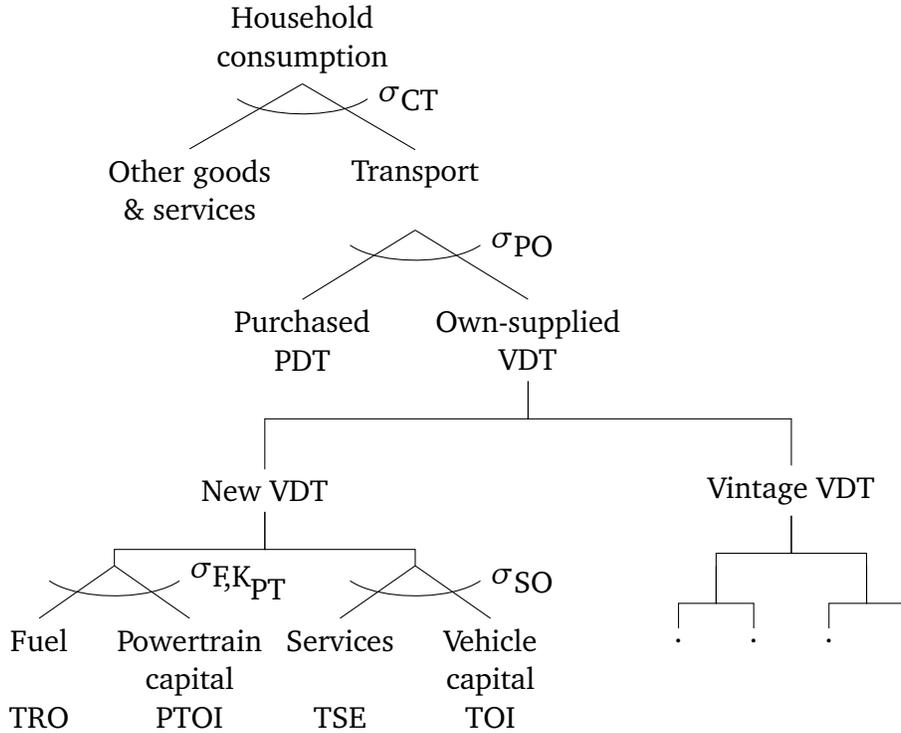


Figure 2-2: Consumption structure for household transport (Karplus, 2011). Elasticity subscripts indicate *other consumption vs. transport*; *purchased vs. own-supplied transport*; *fuel vs. powertrain kapital*; and *services vs. other industrial capital*, and abbreviations for inputs to own-supplied transport are given. The inputs to the vintaged sector are identical to those for new own-supplied transport, only in fixed ratios.

was disaggregated as shown in Figure 2-2. Instead of consuming directly from the same TRAN production sector used as an intermediate input to other production sectors, the representative household in each region chooses a bundle consisting of TRAN sector output (which is comprise of commercially-operated freight and passenger-sector transport)—referred to as *purchased* transport—and *own-supplied* transport. In order to consume the latter, the household must either purchase new vehicle capital, or use existing vehicle capital. New vehicles become vintage vehicle stock in subsequent periods. This structure allows for flexibility in the fuel efficiency of the vehicle at time of purchase as governed by the elasticities in Figure 2-2, which is then fixed once the new fleet is vintaged. Unlike other EPPA sectors, there are two vintages of vehicle capital, new and used, given the paucity of data available to parameterize the fuel efficiency of every vintage in every region. Finally, each type of vehicle powertrain capital is repre-

Symbol	Powertrain	Energy input(s)
ICEV	Internal combustion	ROIL
PHEV	Plug-in hybrid-electric	ROIL, ELEC
BEV	Battery electric	ELEC
CNGV	Compressed natural gas	GAS

Table 2-2: Energy inputs to own-supplied transport, by powertrain type.

Listing 2-1: MPSGE production block for household transport.

```

$PROD:HTRN(R) s:htrn_sigma(r) b(s):0
O:PTRN(R) Q:(TOTTRN(R) - XBAR(R))
* Own-supplied:
I:PHVTN(R) Q:(OWNTRNNEW(R) - (OWNTRNNEW(R) / OWNTRN(R) * XBAR(R))) b:
I:PHVTU(R) Q:(OWNTRNVIN(R) - (OWNTRNVIN(R) / OWNTRN(R) * XBAR(R))) b:
* Purchased transport:
I:PA("TRAN",R) Q:PURTRN(R) P:PCO("TRAN",R) A:RA(R) T:TP("TRAN",R)

```

sented by a distinct production function, which allows distinction between power-train types on the basis of the input to the the “Fuel” bundle, as shown in Table 2-2.

Listing 2-1 gives a portion of the MPSGE code used to model the production of PTRN (“Transport” in Figure 2-2). In a two-vintage version of structure used elsewhere in EPPA5, a fixed portion of own-supplied transport comes from vintage vehicles, and the remainder from new vehicles. Vintage powertrain capital (PHVTU(R)) has a fixed production structure to represent the impossibility of altering significantly the underlying efficiency of the powertrain in used vehicles.

2.2 Data sources and representing growth to the present

In order to apply EPPA5 to a study of Chinese household transport, the model structure was adapted to better represent the relationship of household transport demand, income and rapid economic growth. The work in Paltsev et al. (2004); Karplus (2011); Karplus et al. (2012b) and like studies focused on the United States household transport market, which is more mature, better studied, and has broad features not in common with the Chinese market. In particular, the U.S. displays roughly constant per

capita ownership, meaning that most sales can be related to replacement of vehicles scrapped by current owners, or small changes in GDP (Greenspan and Cohen, 1999). In China, on the other hand, a large portion of sales are to new owners, and per capita ownership is growing. These differences warrant attention to the data sources and modelling structure used to represent China and other rapidly developing regions, to ensure the representation is as suitable as in the region for which it was initially developed.

One challenge in performing such physical account calibration of a CGE model in China is availability of data. In the area of transport, OECD (2012); Euromonitor International (2011) and International Road Federation (2010) each republish some series from the National Bureau of Statistics of China's *China Statistical Yearbooks* without adjustment and with limited detail on data sources and methodology.³ Another issue is the great diversity of vehicle types visible on Chinese urban roads. Many of these, including bicycles, electric scooters and motorized carts, are not registered or regulated in the same way as cars and trucks, and so do not appear in the same statistical accounts. Further difficulty arises from the fact that electricity use due to electric scooters and vehicles is, at the moment, not reported as a transport energy use quantity, and thus not distinguishable from general household consumption, making calculation of on-road energy economy for these vehicles difficult (Weinert et al., 2007).

The recalibration uses data on household expenditures on new vehicles and highway distance travelled per vehicle from Euromonitor International's *Passport GMID*; and registrations from the International Road Federation's *World Road Statistics (International Road Federation, 2010; Euromonitor International, 2011)*. The process used is as described in Appendix A.3 to Karplus (2011), implemented using the code given in Appendix A, and the resulting figures appear in Table 2-3. Particular changes here which do not affect China include the use of approximate values from analogous regions at some stages of the calculation, rather than round figures.

³Additional detail about statistical sources is discussed in Appendix C.

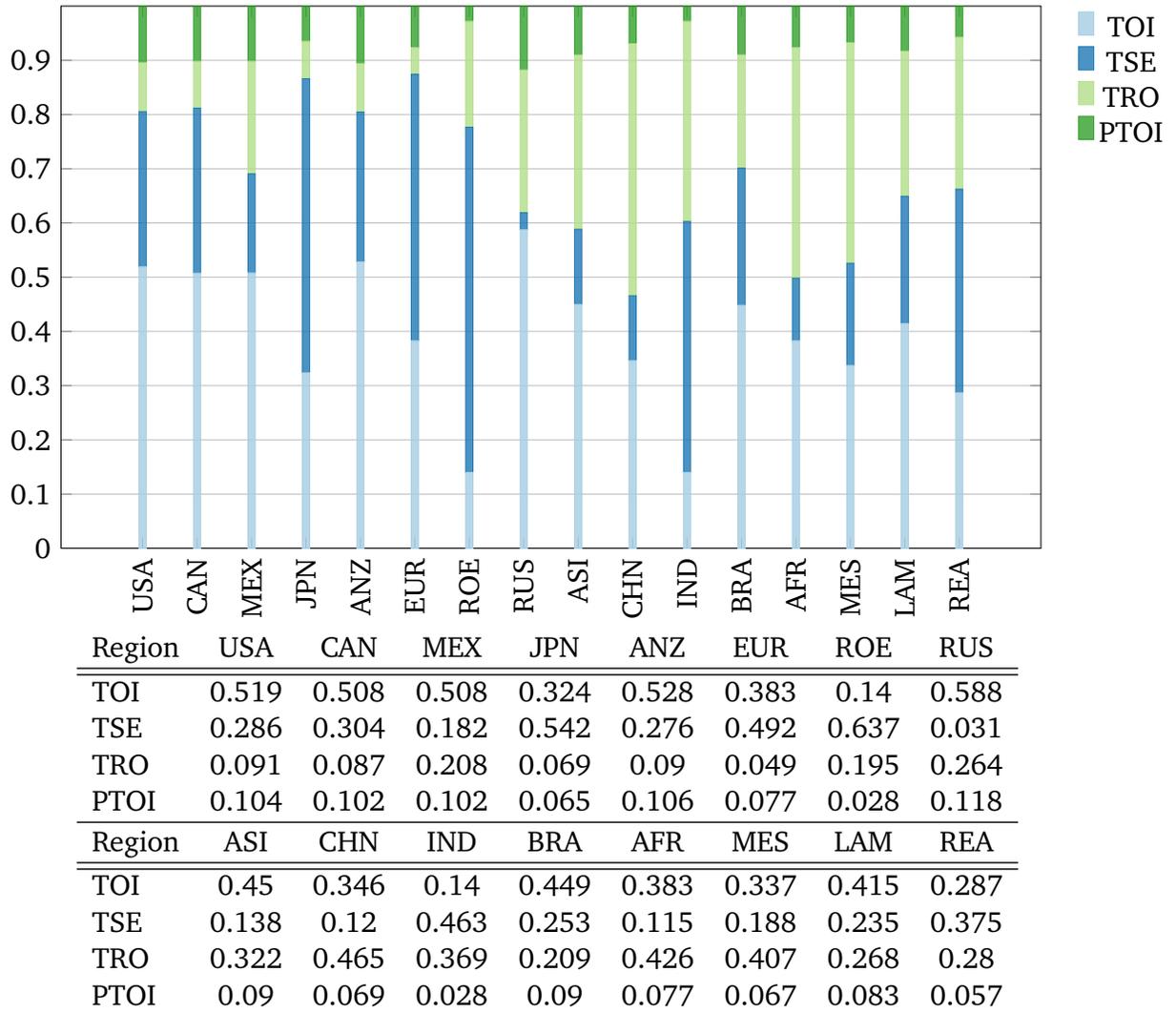


Table 2-3: Shares of input to the per-distance cost of own-supplied transport. As shown in Figure 2-2, the inputs are: TRO refined oil, TSE services, PTOI industrial (OTHR sector) output representing powertrain capital, TOI industrial (OTHR sector) representing non-powertrain capital.

2.2.1 Adapting to rapid growth in Chinese vehicle stock

Simulating changes in expenditure shares over time that are unrelated to price requires moving away from the homothetic preferences assumption. Homothetic preferences have an income elasticity of 1.0, so that the fraction of each type of good or service consumed by the representative household is maintained even as total consumption grows (Rutherford, 1995). For mature transport markets in the OECD where per-capita vehicle ownership and travel demand are constant or have an income elasticity of about 1 (Dargay et al., 2007), this is largely an appropriate structure.⁴ But in a rapidly-motorizing region such as China where, for instance, annual automobile sales are growing at a multiple of the GDP growth rate (Wang et al., 2011), the CES consequence that expenditure on purchased and own-supplied transport—and corresponding imputed physical quantities—grow at the same rate as GDP leads to output which does not match observations.

The household transport sector as modelled by Karplus (2011) uses a Stone-Geary utility function over purchased and own-supplied transport,⁵ but recalibration of the extra parameters provided by this formulation, even with a very high income elasticity of household transport demand, is not sufficient to match observed growth through 2010. Therefore, after the general equilibrium is determined in each model period, the reference quantities are adjusted so that China's total vehicle stock in 2005 and 2010 matches data from the National Bureau of Statistics; vehicle stock in the model is calculated by assuming that each individual vehicle uses the same quantity of non-powertrain (OTHR sector) input to own-supplied transport as in the benchmark year.

2.3 Scenarios and policies modelled

Combinations of three distinct scenarios of transport demand, and three economy-wide policies on CO₂ emissions, were taken to form nine configurations of the EPPA model.

⁴Some evidence exists that spending on vehicle transport (Davis et al., 2012) and transport generally is not entirely stable in these markets with rising wealth.

⁵Visible in the reference quantities (Q:) supplied in Listing 2-1.

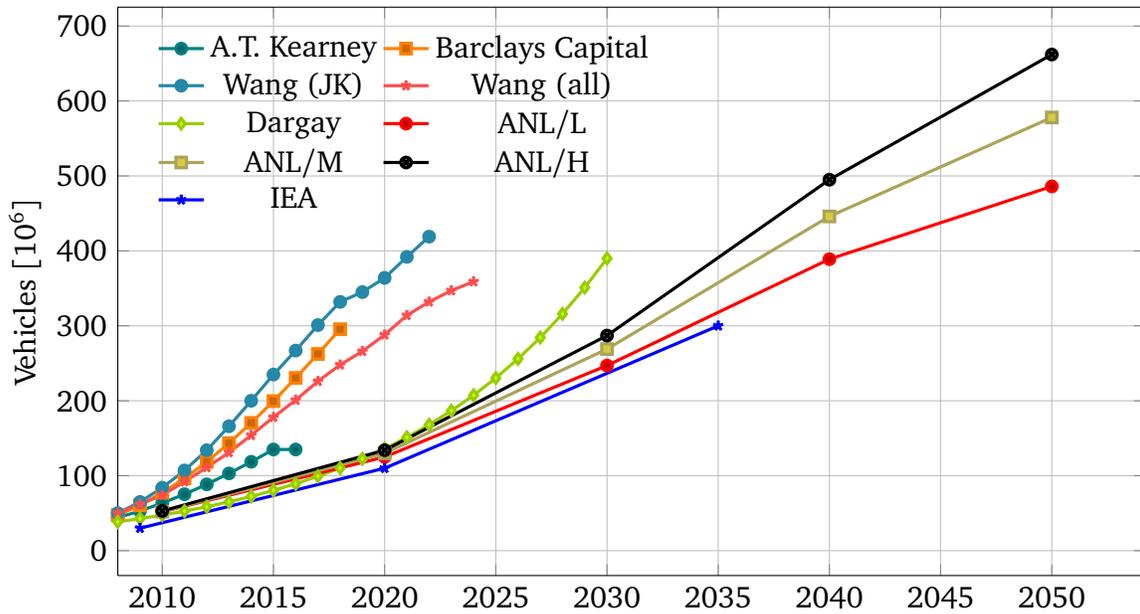


Figure 2-3: Projected growth of total vehicles in use (stock) through 2050 by various studies. “Wang (JK)” and “(all)” refer to the projections from Wang et al. (2011) using the Japan/Korea and all-countries panels, respectively. The Argonne National Laboratory (ANL) Low-, Medium- and High-growth projections are from Wang et al. (2006); others from Dargay et al. (2007); A.T. Kearney (2011); Barclays Capital (2011); International Energy Agency (2011).

The scenarios and policies are described separately here.

2.3.1 Scenarios of transport demand growth

As shown in Figure 2-3, forecasts of vehicle stock in China vary widely. Other authors have noted that from the early 2000s through 2011 most studies underestimated the rate of growth of the privately-owned vehicle fleet; projecting 2010 vehicle populations of 47-54 million against an actual figure of 78 million (Wang et al., 2006; Chamon et al., 2008; Kobos et al., 2003; National Bureau of Statistics of China, 2012). This disparity is due primarily to the underestimation of new vehicle sales growth over the same period. Studies also differ in the assumptions on vehicle fuel efficiency and annual distance traveled per vehicle, leading to a wide range in projections of refined oil demand and GHG emissions.

The variety of outcomes also reflects structural uncertainty: different models of the

Scenario	Household transport						Purchased
	2005	2010	2015	2020..2035	2040	2045, 2050	(all periods)
Low	1.085	1.65	1.2	1	1	0.95	1
		<i>1.79</i>	<i>2.15</i>	←	←	<i>1.94</i>	
Medium	1.085	1.75	1.7	1	1	0.9	0.875
		<i>1.90</i>	<i>3.23</i>	←	←	<i>2.61</i>	<i>0.263</i>
High	1.085	1.8	2.7	1	0.85	0.85	0.75
		<i>1.95</i>	<i>5.27</i>	←	<i>4.48</i>	<i>3.24</i>	<i>0.0563</i>

Table 2-4: Share-forcing factors for household and purchased transport consumption, by scenario. Incremental effect for each period in roman, cumulative effect in italic; the cumulative effect given for purchased modes is in 2050.

relationship between household transport indicators and a plethora of factors reflect claims about the relative importance of different causal relationships. For instance, a Gompertz function of income (as in Dargay et al., 2007) or time imposes a technology-adoption narrative: ownership before availability of a technology is effectively zero; then grows at a parameterized rate until it approaches, asymptotically, some maximum per-capita level, at which point it is said to have *saturated*. Alternately, Kobos et al. (2003); Chamon et al. (2008); Wang et al. (2011) use a panel method, relating China’s adoption of vehicles to the historical trend in other countries, aligning series of annual growth rates according to ownership levels, and averaging across nations to produce projected growth rates for China—yet authors differ on the appropriate set and periods of international comparators.

In the present and following chapter, the concern is not with resolving this structural uncertainty, but with examining the interaction of growth with energy and emissions policy, most importantly the effect of prices. Accordingly, the literature projections are taken, as given, to bracket uncertainty in the Chinese vehicle market. Three scenarios of household transport demand growth are developed which attempt to drive vehicle ownership to the highest, lowest and average ownership values. In order to impose these on the model, the same method of shares adjustment described in Section 2.2 is applied. However, the use for 2015 and onwards is a projective use rather than one based on history. Table 2-4 gives the share-forcing factors used within EPPA, as well as

an extra set of factors for the purchased portion of household transport expenditure. These factors model an expectation that highest demand for ownership and use of vehicles will occur under both rising total demand and consumer preferences which shift away from low-speed purchased modes over time; so that a future with the highest demand for vehicles can be expected to also have a depressed share for low-speed purchased modes (Meyer et al., 2007; Schäfer et al., 2009). More comment on this assumption is given in Section 2.4.

2.3.2 Greenhouse gas emission policies

The base policy for EPPA is a *business-as-usual* (BAU) projection in which no control of any type is enacted on energy use or emissions. In the no-policy configuration, backstop technologies are inactive.

A *550 ppm climate stabilization policy* is adopted from Paltsev et al. (2012) wherein each region, including China, participates in a CO₂-only cap scheme designed to limit atmospheric greenhouse gas concentrations to 550 parts per million by 2100. The policy begins in 2020 and follows the same trajectory of percentage reductions relative to reference in every region. No trading between gases or regions is implemented; China cannot achieve its reduction target through abatement of the other Kyoto Protocol gases modelled in EPPA.

This policy descends from the European Modelling Forum scenarios described by Clarke et al. (2009) and is extremely stringent, much more so than any policy proposed by China itself or suggested for it by others. However, it has utility from a methodological perspective: by creating a large disruption relative to business-as-usual in the direction of lower emissions, it enables identification of the effects of policy on the household transport sector in particular, and of the differences between such effects across the three demand scenarios described above. Household transport is not a source of cost effective abatement opportunities relative to other sectors, so mild economy-wide constraints result in reductions being taken in other sectors (Karplus et al., 2012a); in reaction to successively more stringent policies, each part of the economy with a lower

marginal cost of abatement will be engaged in sequence before household transport shows any response. In short, the purpose of studying this policy is to make readily apparent the distinctions from the counterfactual.

Finally, a *FYP emissions-intensity policy* extends, through 2050, China's commitment in the Twelfth Five-Year Plan (12-FYP, 2011–2015 inclusive) to a 17 percent reduction in the CO₂ emissions intensity of GDP, or a reduction of 3.66 percent per year on average. In each subsequent period, the emissions per unit GDP are constrained to be 17 percent less than in the previous period, as follows. First, the business-as-usual intensity is calculated for 2010. Then, for 2015 and subsequent periods, a target intensity after successive 17 percent reductions is calculated. The resulting intensities for each period are multiplied by business-as-usual GDP projections to yield total CO₂ emissions, which are implemented in EPPA as caps.

The purpose of modelling such a policy is to implement a cap on emissions which has some actual effect on the economy, including possibly household transport, yet bears resemblance to previous, current and aspirational goals actually stated by the Chinese government. In international discussions, China has announced an intent to cut energy intensity 40 to 45 percent in the period 2005–2020 (Casey and Koleski, 2011). With the achievement of a 19 percent reduction in the Eleventh Five-Year Plan (11-FYP, 2006–2010 inclusive) (Deutsche Bank, 2011) and assuming the FYP12 target is met, this leaves a reduction of 11 to 18 percent to be made in the Thirteenth Five-Year Plan period (2016–2020 inclusive). Extrapolation of the 17 percent target to 13-FYP is within these bounds; the FYP extension policy simply assumes continual renewal of the same target through a hypothetical 19-FYP in 2046–2050.

The maximum amounts of carbon dioxide emissions mandated in each policy are shown in Table 2-5, as well, for comparison, the unconstrained amounts in the reference scenario and in the model before the adjustment to observed vehicle stock growth described in this chapter.

Year	CO ₂ emissions [Tg = 10 ⁶ t]			
	Unadjusted	Reference	FYP	Stabilization
2004	5074	5074	5074	5074
2005	4823	4842	4842	4842
2010	7871	8051	8049	8049
2015	9672	10178	10174	10174
2020	11311	12042	11139	3871
2025	12703	13702	13076	3592
2030	13874	15108	14044	3308
2035	15093	16611	14528	3149
2040	15539	17198	14043	2907
2045	15894	17607	14043	2664
2050	15990	17829	13559	2422

Table 2-5: China CO₂ emissions, all sources, in the reference run in the medium-demand scenario, and under two policies modelled. “Unadjusted” column gives the business-as-usual or reference quantity in the model as configured prior to the model updates described in Section 2.2.

2.4 Extensions

The following potential extensions of the work would offer further improvement. EPPA has been used to study transport in the aviation sector (Winchester et al., 2011), and a parallel version to EPPA-HTRN has been developed which disaggregates civil aviation from household purchased transport (labelled EPPA-A, Gillespie, 2011). Historical data (National Bureau of Statistics of China, 2012) show passenger aviation growing in China in an absolute sense, albeit with a small share of overall travel. The analysis of Schäfer (2006) places this within a trend of shifts from lower- to higher-speed modes with increasing income. However, as noted in Section 2.3, the consumption structure for household transport used here allows only relative share changes between own-supplied (private vehicle) travel and a bundle including all other purchased modes, including aviation. Civil aviation, high speed rail, conventional rail, city buses, subways and other purchased modes differ greatly in their per-distance price and energy and emissions intensity. Applying the methodology of this chapter to a model with the combined features of EPPA-A and EPPA-HTRN would allow modelling a three- instead of two-way mode split to separate movement from low-speed purchased transport to

own-supplied transport on the one hand, and simultaneous shifts or concurrent growth in own-supplied transport and higher-speed purchased modes, namely aviation, on the other hand. As well, more sophisticated scenario design could be pursued which would capture shifts not possible in EPPA5 alone.

The Five-Year Plan extension policy used here is modelled as absolute emissions caps calculated *a priori* from decreasing emissions intensity values and the GDP figures for the business-as-usual case. If the model solution GDP in a period is less than business-as-usual—as is the case here—then the cap allows a slightly greater emissions intensity than the one used in the calculation. This effect compounds over periods. Because, as noted, the FYP policy is lenient, this error is not large; an average of 16 percent energy intensity reduction is achieved in each five-year period from 2015 to 2050. However, the error could be limited by altering the model structure to calculate the next-period cap from each period's GDP and emissions outputs; or better still, to constrain intensity directly.

Chapter 3

Results: Effects of rising passenger transport demand and policy

This chapter examines the outcomes of the application of the model with new China transport sector detail and scenario and policy modelling described in Chapter 2. The presentation is organized in three sections: Section 3.1 deals with the own-supplied household transport sector and private vehicles specifically, Section 3.2 concerns energy and emissions quantities and prices; and Section 3.3 with aggregate travel and economic behaviour, including quantities of travel by mode, aggregate consumption and expenditures on transport. Within each section, the distinctions between the low-, medium- and high demand scenarios under business-as-usual are discussed, as well as the impacts of the two policies, and followed by any important differences between the model response to each policy, across scenarios.

In interpreting the projection outcomes, it is important to note that the model update for China described in Chapter 2 and absence of policy before 2015 mean that results from the 2005 and 2010 model periods cannot be regarded as predictive. The salience of results under the Five-Year Plan extension policy depends on the central government's willingness continue specifying targets, like those in 12-FYP, that are intensity-based and only constrain activity (including transport) slightly. Although the results of the 550 ppm climate stabilization policy will be shown to be dramatic, this is one example of the effects of absolute, rather than intensity-based targets—the type

that must be applied to total emissions to have a significant impact on the extent of climate change that is likely to occur. If China participates in an international agreement under it which bears a smaller share of the global reductions burden proportional to its base-year emissions, the resulting caps would be higher and the effects shown here would be smaller in degree, yet similar in type. Additionally, in several of the plots there is a larger change from 2015 to 2020 under the stabilization policy than between subsequent periods; this is because EPPA does not represent forward-looking behaviour, nor is it constructed with the time resolution for modelling policy phase-in over periods of months or years—it is focused on the long term. As noted in Section 4.1, non-binding limits and quotas are sometimes introduced in pilot programmes, and only scaled up once details of administration and operation are resolved. For economy-wide climate policy, this strategy would likely be employed, diffusing the sharp impact of policy. Implications for non-economy-wide policy, specific to the transport sector, are also discussed in Section 4.1.

For each region and each economic sector or subsector, the model solution yields both prices and quantities in the base and each projected period; the product of price and quantity is economic value. Physical quantities are reported according to the relationship to price, quantity or value in the benchmarking process and technology changes as modelled; where relevant, this detail is given before the results are presented. Together, these physical and economic outputs, as well as exogenous inputs—especially the population forecast—provide some insight into the consequences of policy action (or inaction) for energy, environmental, and economic outcomes.

3.1 Private vehicles

In Figure 3-1, a comparison is made between non-CGE projections of total private vehicle stock from literature and the range of EPPA outputs across scenarios. The medium-demand, business-as-usual projection reaches a total stock of 496 million in 2050, only slightly above the low-growth scenario of Wang et al. (2006). The range between the stocks in the high (530 million) and low (448 million) demand cases is 16.5 percent of

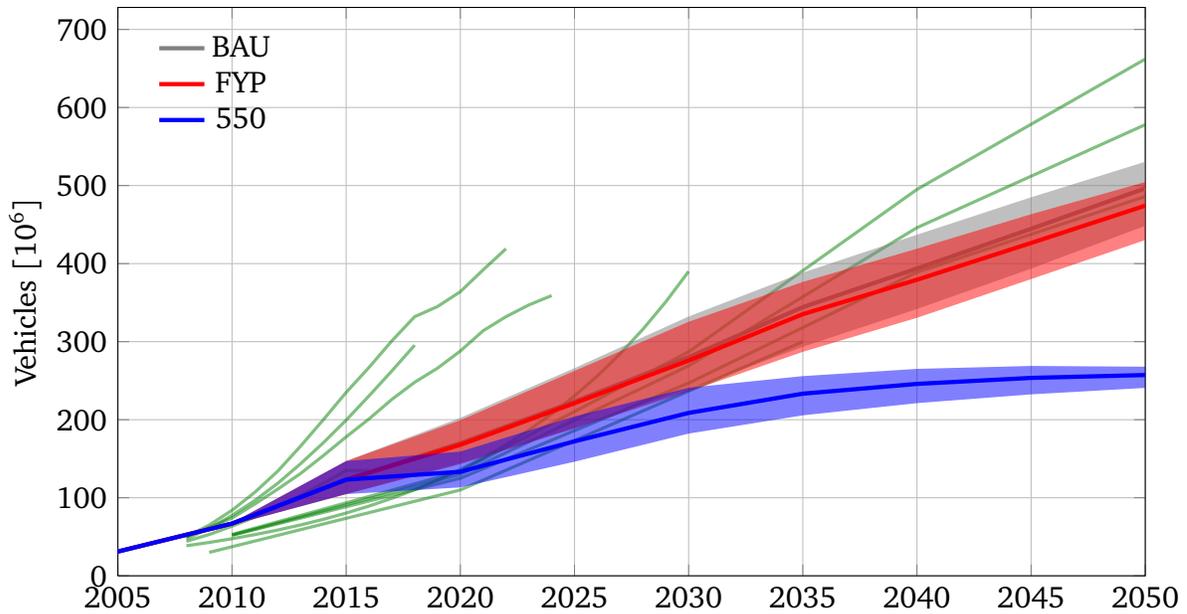


Figure 3-1: Vehicle stock, by year. Range of EPPA projections displayed as a band between the low- and high vehicle demand scenarios, with the medium scenario as a solid line; overlaid on projections from literature as in Figure 2-3 (green).

the median value, a smaller range than in the literature. The countervailing effects of high prices for fuel combined with low household income (explored below in Section 3.3) serve to limit the effect of the large demand for own-supplied transport in the high projection, and fleet growth, while rapid and increasing at 7.9 million (in 2010–2015) to 10.9 million (2045–2050) vehicles per year in even the lower projection, does not display as noticeable an exponential trend as in other studies.

In a relationship that is visible across model outputs, the policy based on extension of the Five-Year Plan carbon-intensity reduction target has only a modest effect, so that the projections for total stock under this policy (430 to 504 million vehicles) substantially overlap those from the no-policy scenario. Until 2035, the difference is less than 5 million vehicles in all cases. The stabilization policy shows the effect of strong economy-wide climate constraints on vehicle ownership. Total fleet size plateaus, reaching a maximum of 269 million vehicles in the high demand scenario.

The same effect is visible on a per-capita ownership basis in Figure 3-2. Although

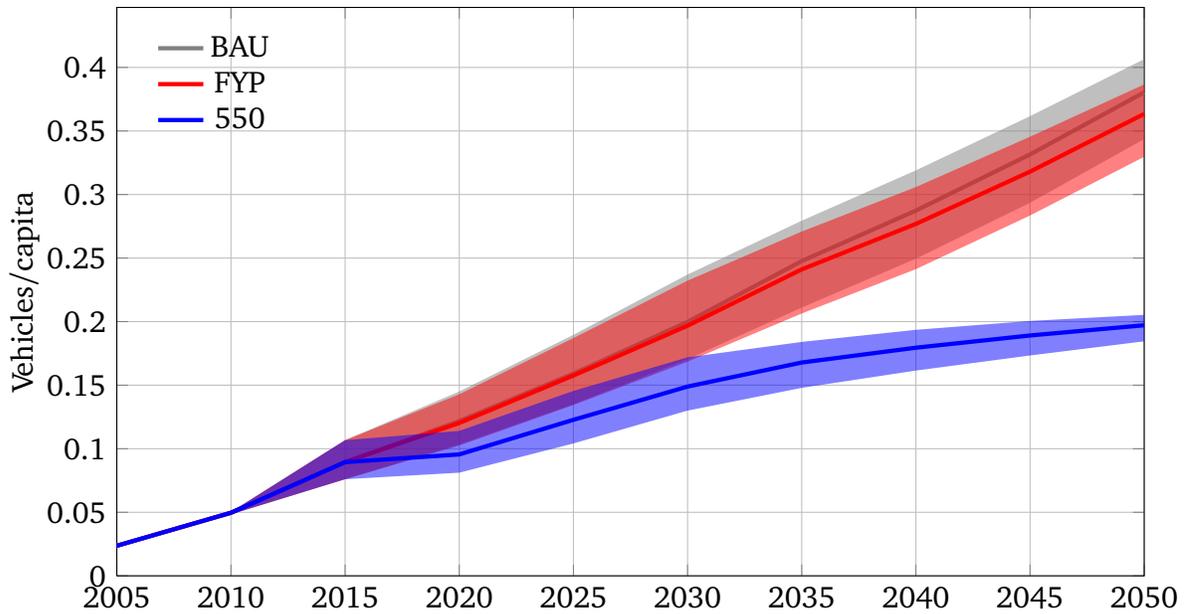


Figure 3-2: Per-capita vehicle ownership, by year. Range of EPPA projections displayed as a band between the low- and high vehicle demand scenarios, with the medium scenario as a solid line.

ownership continues to increase from 2045–2050, the Chinese population projection used in EPPA has a peak in 2035, and a small decline population slightly outweighs the increase in ownership to produce a smaller fleet under the stabilization scenario. If the trend continues, the total vehicle stock peaks, representing a saturated or mature market—albeit at a level of 200 vehicles per thousand capita, less than half of that in current mature markets such as the European Union, at 475 per 1000 capita (International Energy Agency, 2011). In the reference scenario, or under the FYP extension policy, ownership continues to grow through mid-century.

Within this smaller total, however, the same high prices of fuel and efficient vehicle capital make alternative fuel vehicles¹ more attractive, because of the option of using a bundle of (less expensive) electricity and refined oil, instead of refined oil alone. Figure 3-3 gives the share of own-supplied transport obtained using the backstop PHEV technology, which is available from 2020 in the model.² The powertrain capital por-

¹The term used in Chinese policy is “new energy vehicle” (NEV).

²For comparison, Gong et al. (2012) note an aspiration target of NEVs representing 5 percent of all new vehicle sales in 2011 was missed widely, despite subsidies.

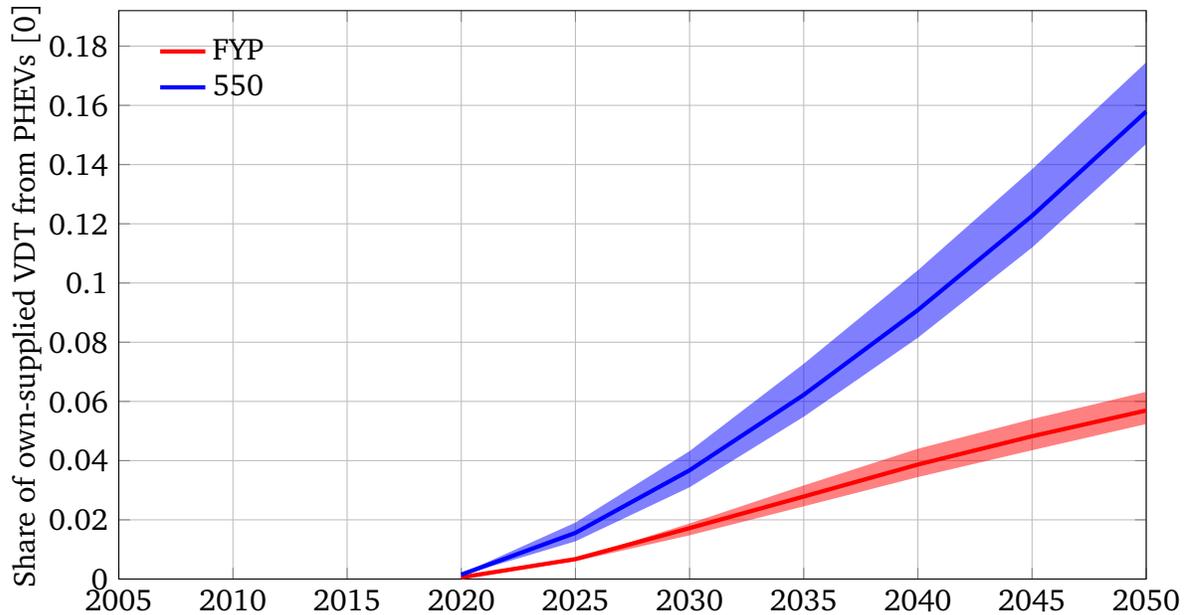


Figure 3-3: Fraction of own-supplied transport volume from plug-in hybrid-electric vehicles, by year.

tion of expenditure on these vehicles is marked up as 40 percent more expensive than the equivalent input to new internal combustion vehicle transport. No PHEV/NEV usage occurs in the business-as-usual projections, in which all backstop technologies are disabled. Under the FYP extension policy, the share for PHEVs reaches just under 6 percent by 2050. With a 550 stabilization policy, a much larger portion—between 15 and 17 percent—of own-supplied transport is derived from PHEVs by 2050; despite being a consequence of an economy-wide policy, this is roughly in line with the global average under stringent or best-effort fuel economy standard targeting only the purchased transport sector, which achieves a smaller reduction in emissions (Karplus et al., 2012a).

3.2 Transport-related energy use & emissions

Figure 3-4 gives the quantities of primary energy from each type over time, in each of the three scenarios and under the medium demand projection; Figure 3-5 offers the same presentation for the low- and high-demand scenarios. The key feature of

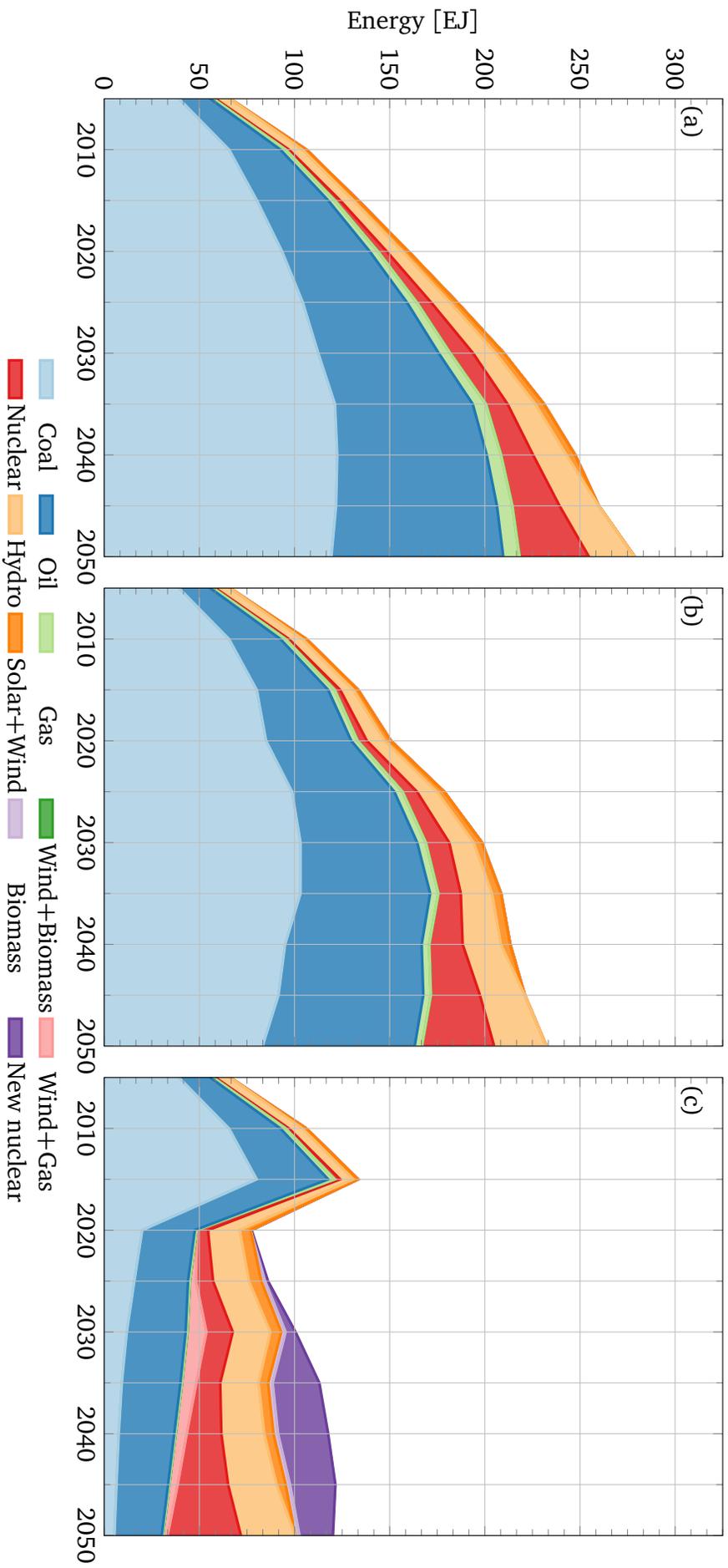


Figure 3-4: Primary energy consumption by type and year in the medium demand scenario, without policy (a), and under the FYP (b) and stabilization (c) policies.

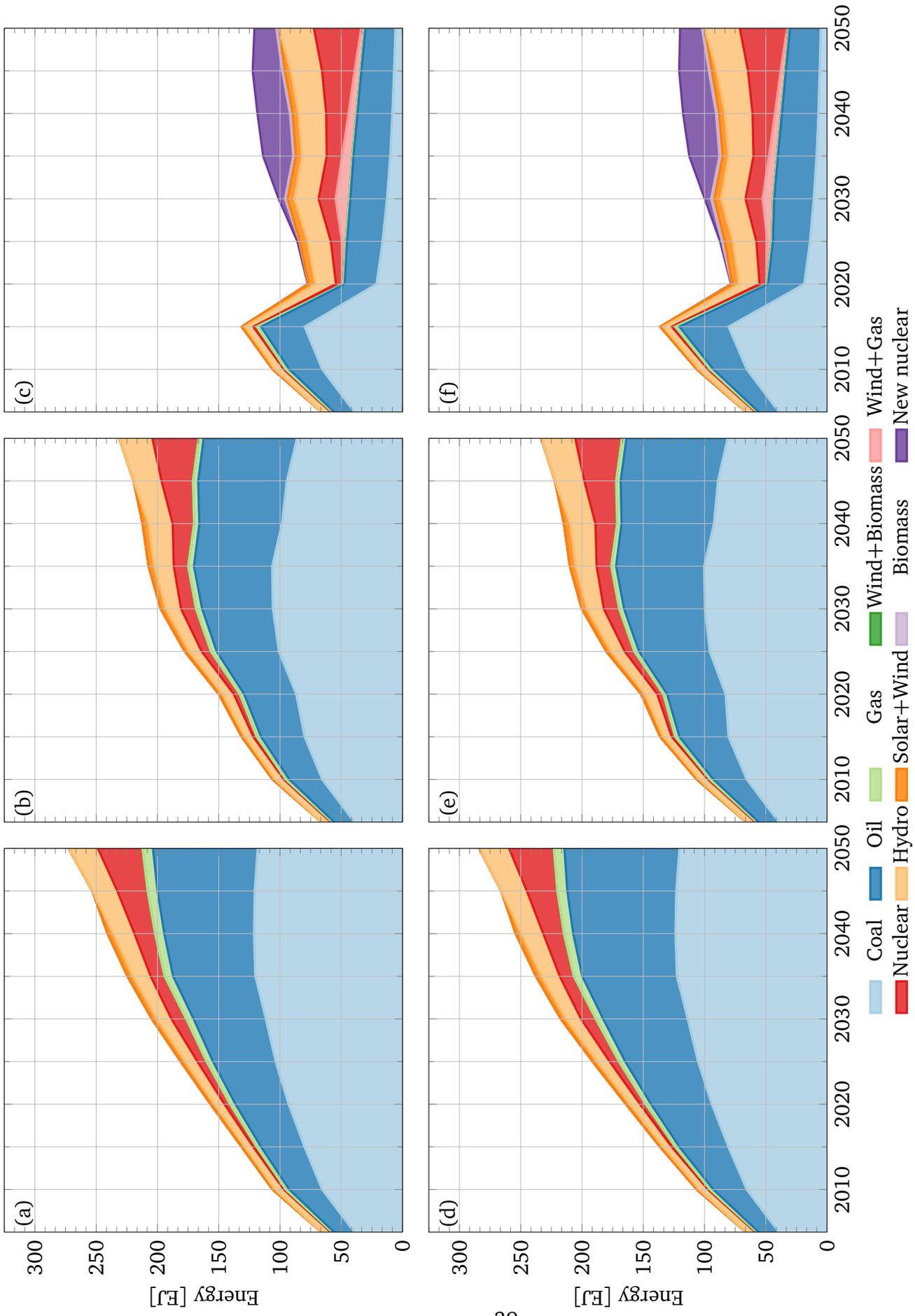


Figure 3-5: Primary energy consumption by type and year, for the low- (a,b,c) and high (d,e,f) demand scenarios; without policy (a,d), and under the FYP (b,e) and stabilization (c,f) policies.

the business-as-usual projection is a sharp rise in oil demand—both as a share of total energy, rising from 24 to as much as 33 percent, and in absolute terms, where the 2004–2050 increase is by a factor of 5.1 to 5.6 depending on demand. The increase is especially significant in relation to its effect on demand for imported oil and exposure to energy security concerns, as discussed in Section 4.1; refined oil demand has not ceased growing in the period 2045–2050 of the reference case.

The FYP policy results emphasize the limited effect of this policy, while Figure 3-4(c) and Figure 3-5(c,f) reveal a number of interesting consequences of demand for own-supplied transport. When the stabilization policy begins in 2020, there is an immediate and drastic reduction in total energy output, by 41–42 percent.³ This effect differs across energy types. Coal-fired electricity generation, for instance, is an emissions-intensive sector with multiple opportunities for substitution. In the low vehicle demand stabilization scenario, energy from coal falls by 73 percent from 2015 to 2020, and in the long term is replaced by increased supply from next-generation nuclear, hydroelectric and other renewable power. In contrast, substitution opportunities in own-supplied household transport are limited, and oil demand falls only 27 percent in the period in which the policy is introduced, to a level 40 percent below reference in 2050.

While the impact of different levels of household transport demand on total primary energy is small, focusing on final energy for transport allows the effects of demand to be examined separately from China’s large and growing coal use. Figure 3-6 shows final demand refined oil (ROIL sector) use in the household own-supplied transport sector as vehicle fuel. The reference and FYP extension scenarios, both displaying continued growth, overtake the 2011 U.S. level of about 190 billion gallons per year⁴ by 2020, and approach or exceed twice current U.S. consumption by 2050. Other features of the final energy projection are similar to the vehicle stock results of Figure 3-1, with some differences due to the additional effect of investment in more efficient vehicles. As a result, the FYP projection does not overlap the business-as-usual case as closely.

³Such a decrease is among the reasons such a policy would be unlikely to be adopted by the Chinese central government; to reiterate, it is used here to provide a useful counterfactual.

⁴U.S. EIA (2012), sum of gasoline and distillate fuel oil (diesel).

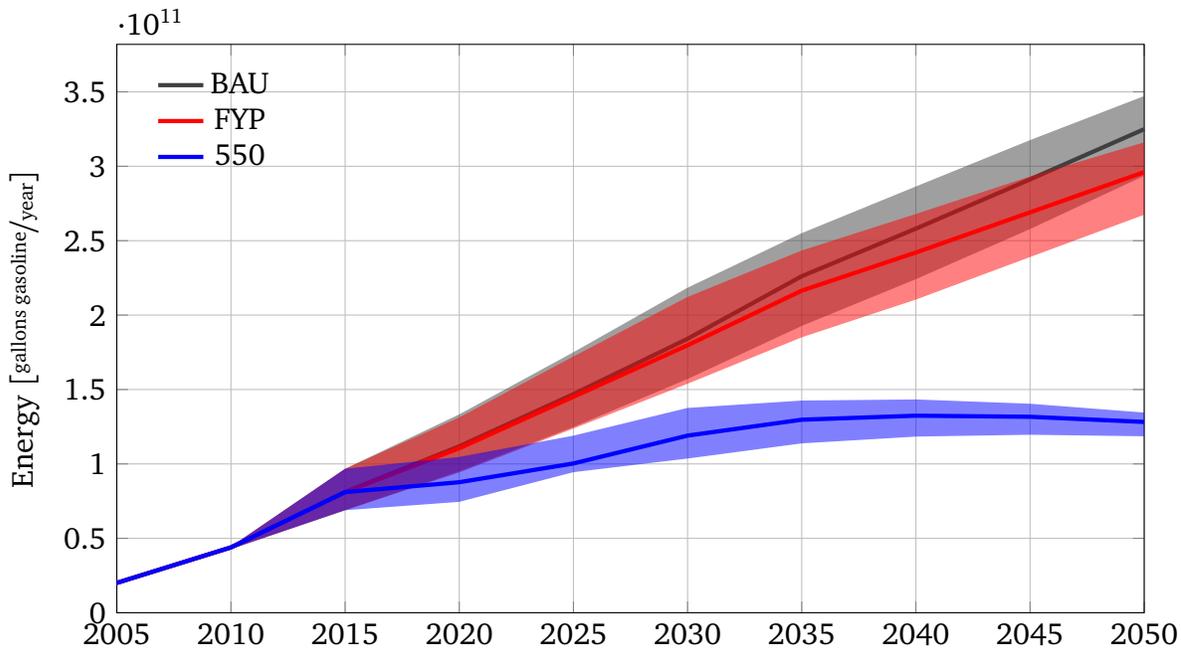


Figure 3-6: Refined oil use in household transportation, by year. Range of EPPA projections displayed as a band between the low- and high vehicle demand scenarios, with the medium scenario as a solid line.

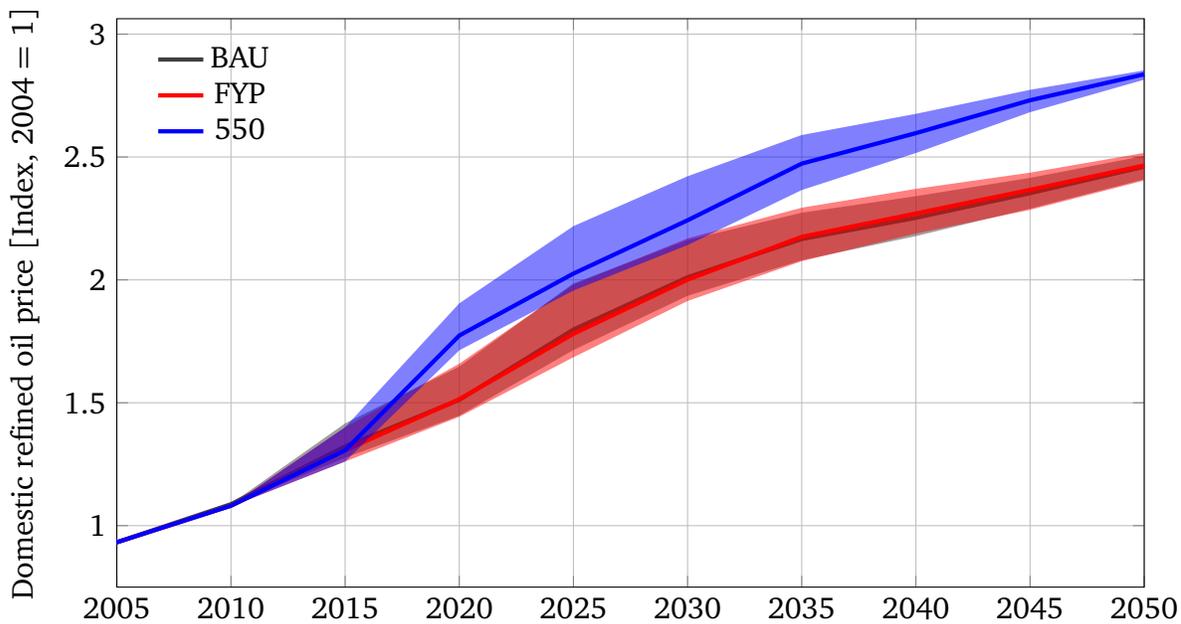


Figure 3-7: Refined oil prices, by year. The BAU projection closely underlies the FYP projection, with a slightly narrower range between the low- and high-demand scenarios.

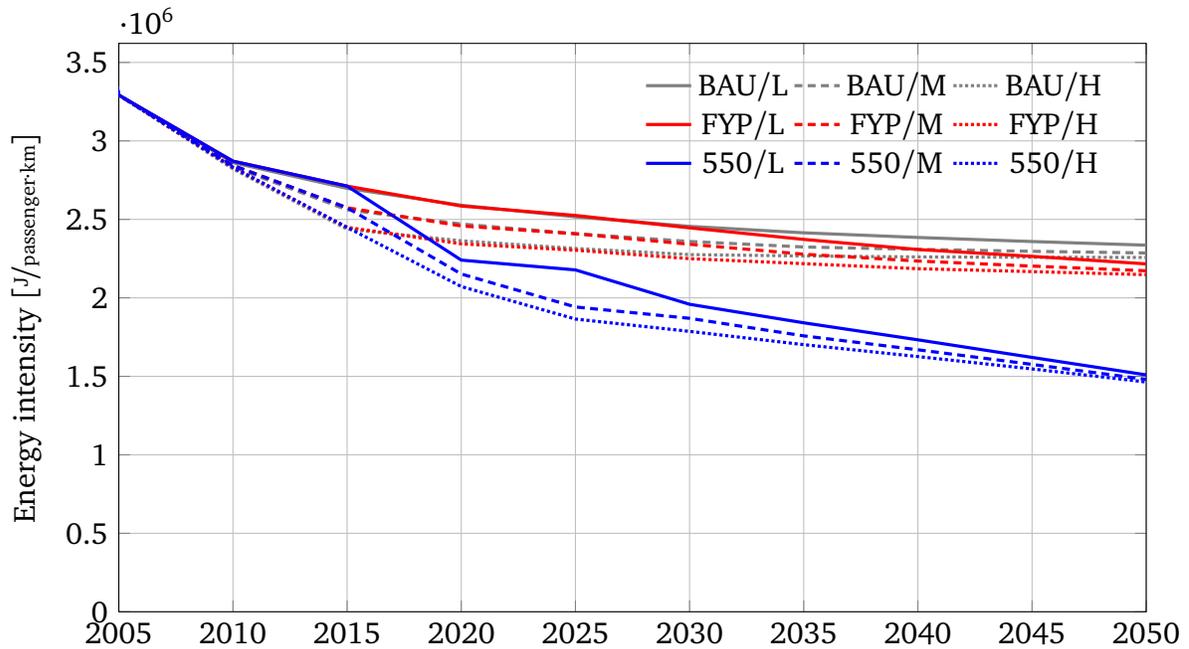


Figure 3-8: Average energy intensity of household transport, by year.

Similarly, where the vehicle stock peaks in 2045 under a stabilization policy, refined oil demand peaks earlier, in 2040, at a level of 132 billion gallons per year in the medium case.

Figure 3-7 gives the unit price of refined oil in real terms, indexed to 1 in the model base year. With increasing demand under business-as-usual, the price doubles by 2025 in the high demand scenario; by 2030 under median demand, and between 2030 and 2035 under low demand scenario; in all scenarios the level eventually reached is two and a half times the base year price.

The FYP policy has a small effect, mainly of increasing the difference between the high and low demand projections in the years 2025–2045. The stabilization policy, on the other hand, causes an immediate and rapid increase in price; doubling from the 2004 price occurs roughly three to seven years earlier, and the price reached in 2050 is 14 percent higher than under the FYP policy or business-as-usual.

Average energy intensity of household transport is displayed in Figure 3-8.⁵ The

⁵Intensity is calculated for each of purchased and own-supplied transport through dividing emissions by passenger distance travelled on each, then computing the weighted average according to distance travelled.

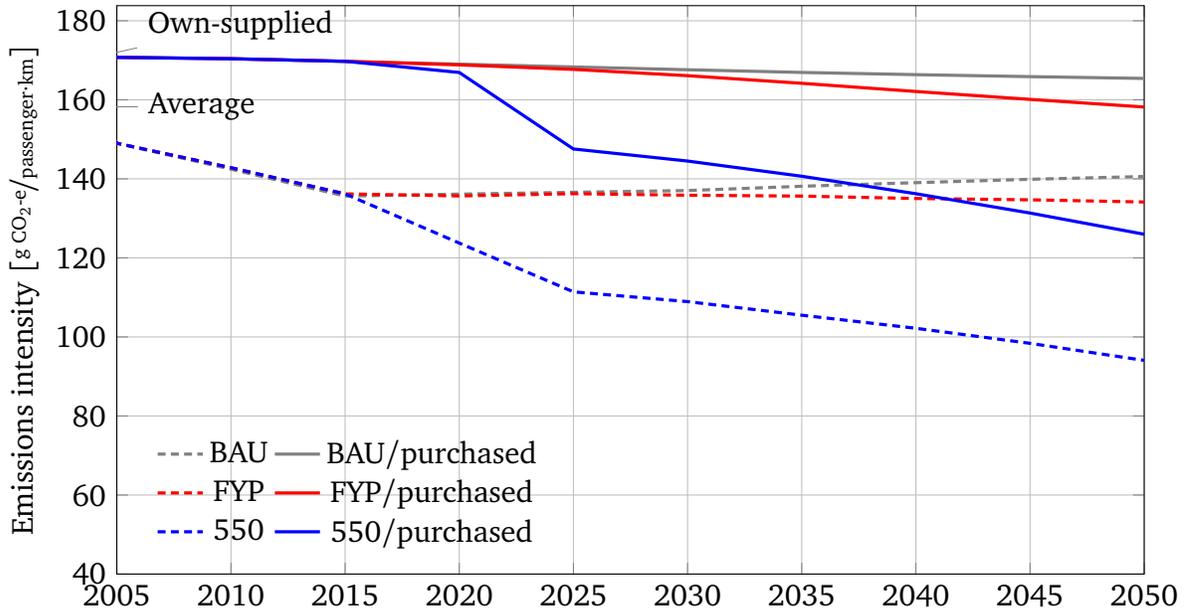


Figure 3-9: Emissions-intensity of transport, by year for the high-growth scenario, with and without policy.

reference projection exhibits the autonomous energy efficiency improvement (AEEI) programmed into the model, with slightly higher demand resulting in a greater investment in more fuel-efficient powertrain capital even as total own-supplied transport increases.

The FYP policy results in an improvement of five percent across cases by 2050 relative to the reference, or 15.6 percent between 2015 and 2050 under medium demand. While not directly comparable (as the per-distance cost of transport varies) total energy intensity of GDP decreases by a much larger 70 percent across the entire economy during the same period. The stabilization policy results in a significant improvement of 35 percent, despite the fact that household transport is one of the more expensive options available for emissions reductions.

In Figure 3-9, the mode-share weighted average *emissions* intensity of transport is contrasted with the intensity of own-supplied transport alone for the high demand projection.⁶ Without policy, and under the FYP extension policy, vehicle transport decreases in emissions intensity, but while the reference decrease reflects only the effect

⁶Note that in this representation an assumption of constant occupancy for private passenger vehicles is used to convert between own-supplied VDT and PDT.

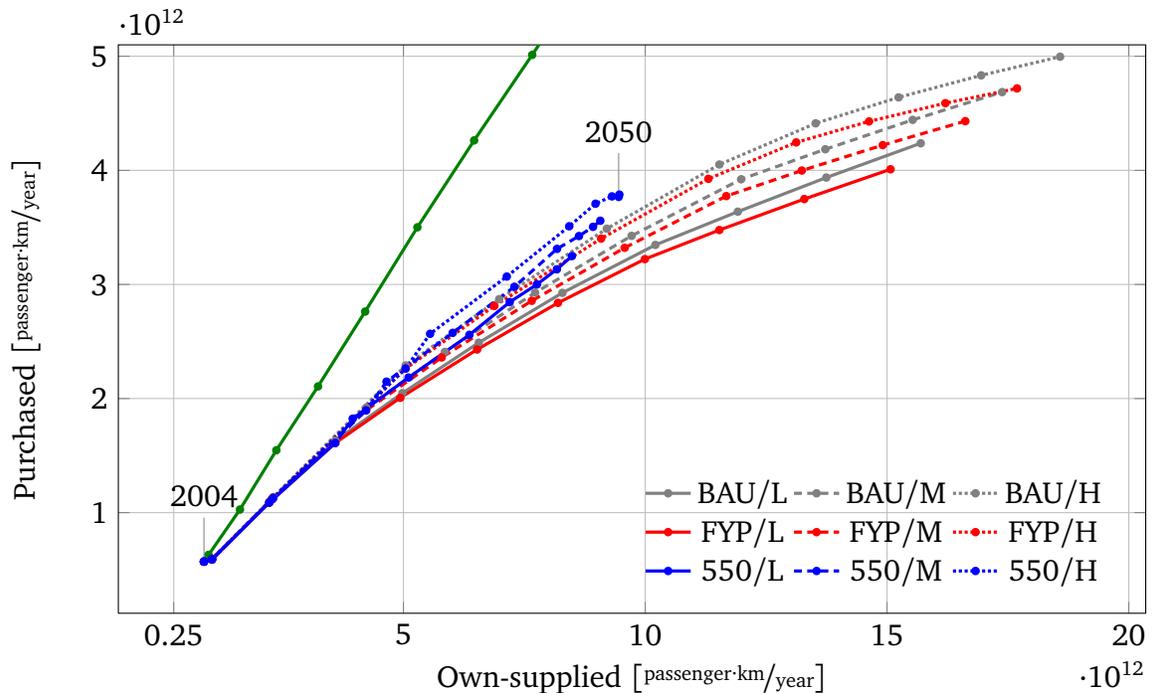


Figure 3-10: Trajectories of purchased and own-supplied transport, by scenario, with unadjusted reference projection (green).

of AEEI on emissions, the FYP extension policy also involves the investment in fuel economy just described. The modelled shift to greater use of own-supplied transport (discussed below) results in a slightly increasing emissions intensity of transport *overall* from 2015 until the end of the projection period, while the effect of the energy-intensity policy is to effectively flatten this slow increase.

Under the relatively aggressive stabilization policy, however, investment in energy efficient powertrain capital becomes an attractive substitute for expensive fuel, and despite a similar shift in modes towards more emissions-intensive private vehicles, overall intensity of transport continues to decline through 2050.

3.3 Transport volume and household expenditure

A notable effect of both policies is to alter the long-run balance between own-supplied and purchased household transport. Figure 3-10 shows *trajectories* of mode share, juxtaposing the total passenger distance travelled by each set of modes, beginning with the

base year near the origin and progressing further away as passenger transport grows with time. The unadjusted (prior to the work described in Chapter 2) reference trend is also shown, to illustrate a hypothetical situation of “constant mode share” growth. The position of the business-as-usual trajectories show their (designed) progression towards more own-supplied transport than in the uncalibrated reference, and also differences in final travel distance. The departure from constant mode share increases over time, reflecting the growing stock of new and vintaged vehicle capital used to provide own-supplied travel.

Under the FYP policy, the mode share between own-supplied and purchased transport does not change appreciably, while total activity decreases; this is visible as similar trajectories, shifted inwards towards the origin. Under a stringent climate policy, on the other hand, the imposed preference for own-supplied transport cannot be met to the same degree as the household budget share does not stretch as far when vehicle efficiency improvements required drive up the cost of vehicles, and are not offset by a reduction in per-distance fuel costs, as shown below. Total travel distance thus eventually ceases to grow around the 2025 level of the no-policy, high demand scenario. The high demand cannot be met without a greater reliance on purchased transport relative to the medium- and low-demand cases, so the mode share remains closer to the unadjusted model’s constant mode share.

Figure 3-11 displays, for both sets of policy scenarios, the percentage change in aggregate consumption measured as equivalent variation relative to the business-as-usual value. Consumption is a measure of welfare, and change in consumption one measure of the economy-wide cost of policy; however, some reference below is also made to GDP (not shown), which includes effects of investment and net exports that may be differently affected by policy, but follows broadly similar trends.

Before the introduction of policy and in the business-as-usual scenario, China’s entire economy grows at 9.5 per year on average from 2005 to 2010, and is projected to grow at 8.8 percent from 2010 to 2015; consumption growth is slightly slower at 9.3 and 8.7 percent per year in the same periods. In the reference scenario the annual average growth rate of consumption later declines from 8.2 percent in the period

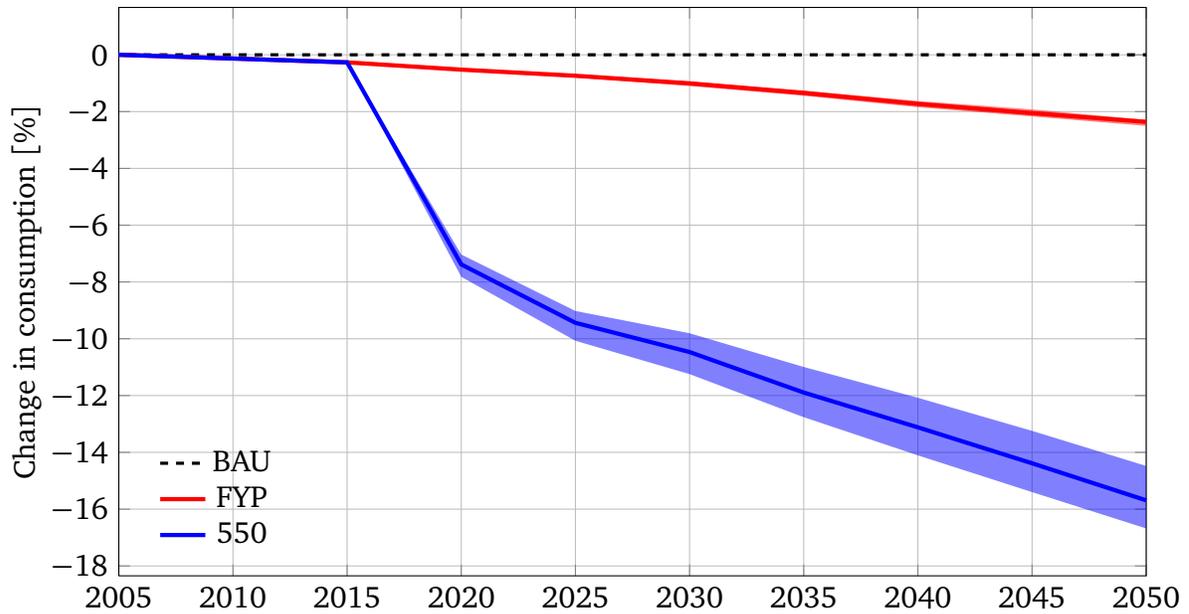


Figure 3-11: Change in consumption due to policy relative to reference case, by year.

2015–2020 to 7.1 percent in 2045–2050.

The FYP policy projection shows a very modest impact. The stated energy and emissions-intensity reduction targets are nearly achieved without policy, and the additional cost of meeting them is small, reaching only 1 percent in 2030 and 2.2 percent in 2050. In contrast, the GHG stabilization policy produces an immediate and drastic reduction in welfare, about opposite in magnitude to one year of GDP growth at recent rates, shrinking to 15–17 percent less than reference by 2050. The continuing large impact makes the cumulative effects of reduced economic activity visible, with the high demand welfare under stabilization policy falling progressively further away from its reference value relative to low demand, reflecting unrealized growth.

In context, the median projection for China’s 2050 per capita GDP under business-as-usual is USD 18,531, between the 2011 levels for Bahrain and the Czech Republic; under the FYP extension policy USD 17,736, comparable to Slovakia; and under the stabilization policy USD 13,960, comparable to Hungary.⁷

Figure 3-12 shows the share of household expenditure on transport, for the own-supplied portion and the total with purchased transport. Without policy or under

⁷All of the three latter are European Union members.

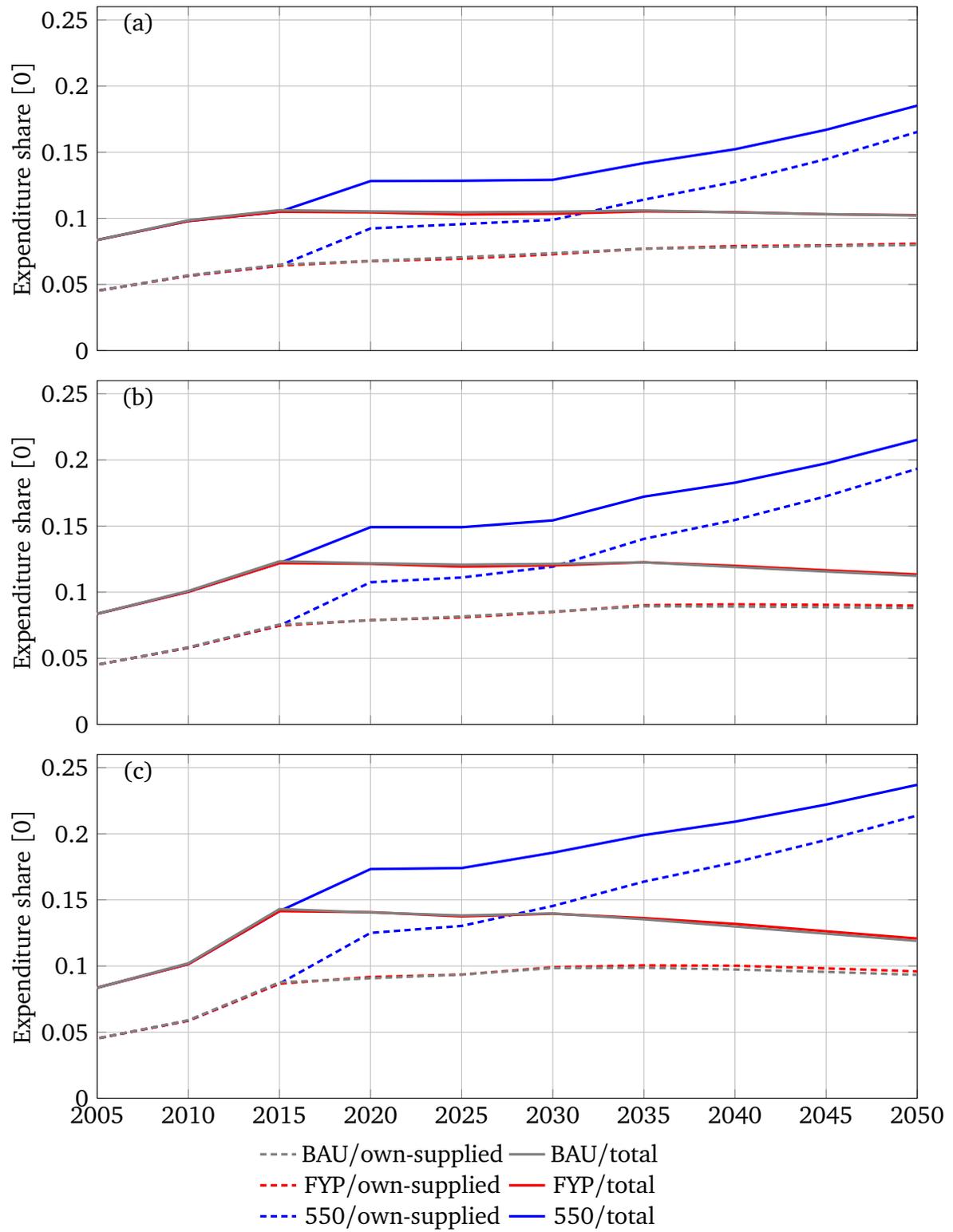


Figure 3-12: Household expenditure shares for transport.

the FYP policy, the travel budget share peaks in 2015 and thereafter declines slightly through 2050. The peaks are at 10, 12 and 14 percent in the low, medium and high demand projections respectively, each within the 5–15 percent range observed by Schäfer (1998) in other, already-motorized countries. The decline of 0.5 to 2 percent reflects fuel savings possible with increased energy efficiency of transport.

In response to the stabilization policy, households are faced with a choice between carbon-priced fuel or more efficient powertrain capital or to reduce demand for transport entirely, all expensive options for providing the combined amount of purchased travel and vehicles imposed in each demand scenario. Along with the effect of reducing travel distance (Figure 3-10), the result is a further increase in the share of the household budget devoted to transport, to 19, 22 or 24 percent of the household budget in 2050 respectively, with the own-supplied portion alone taking 17, 19 or 21 percent of all income. Households are subject to a large price shock in this case as the price of emissions affects their entire consumption bundle, and transport, as an important good, may be a less economically attractive choice for emissions reductions.

Chapter 4

Conclusions and discussion

The foregoing analysis has illustrated ways in which emissions policies representative of current mandates and a long-term climate stabilization target would interact with rapid projected growth for personal transport in China, in particular the demand for vehicles. It shows the impacts of both demand and policy on energy, emissions and economic activity, including transport activity. The continuation of current policies would only modestly restrict demand for vehicle and purchased travel, but would do little for sustainability goals, allowing continued growth in energy use and emissions. An aggressive greenhouse gas stabilization policy effectively caps vehicle ownership as well as total demand for refined oil, limits total passenger distance travelled, and has economy-wide effects.

Insights such as these regarding the effects of future demand for purchased and own-supplied transport will be received and used differently by municipal and central policymakers in China, because their areas of concern, latitude and ability to adopt instruments, and relationship to households differ. While the results of high Chinese demand for vehicles—including congestion, local air pollution, and high refined oil demand—are recognizable from other countries, differences in urban form and governance (Wang, 2010) may mean that direct adoption of policy responses from the West will not necessarily lead to success.

This chapter considers the context of transport policymaking in China and the applicability of the modelling results. While they are not included in the model used,

existing policies and the dynamics between municipal and national-level policymakers (and between different policies of the national-level government) play an important role in China, and are important to consider when interpreting model outcomes. In this context moving to long-term policies that are effective towards climate stabilization goals would be challenged by the lack of agreement on the relative importance of conflicting policy objectives and creating conditions, if possible, where municipal and state administrators act in concert.

I end with a discussion of interesting avenues for extension of this work, and by summarizing the work in its entirety.

4.1 Implications for policy

In this section I discuss policies that have been implemented or are under consideration, and the factors affecting positions of the decision makers involved, before discussing how these relationships might affect the prospects for progress towards more aggressive reductions. I consider several specific policies affecting household transport currently in place under China's central government and the municipal administrators in some of its largest cities. National-level policies include fuel economy, promotion of the automotive manufacturing industry and the growth of NEVs in particular, and the response to the energy security concern of rapidly rising oil imports.

I focus on municipal transport policies from the directly-governed municipalities of Beijing, Shanghai, Tianjin and Chongqing (Figure B-1 in the appendices), because these are among the largest and densest in the world, so economic and environmental externalities of transport are most acute and policy responses more advanced. Urbanization is projected to increase in China to 77 percent by 2050 (UN Population Division, 2012), giving rise to more than 100 cities of 1-2 million (Leaver et al., 2012; Loo and Li, 2006) and many larger cities; the pioneering experiences of the current large urban centres will be looked to for lessons in managing this growth, including in the area of transport. As well government entrepreneurialism is an important feature of policymaking in cities: in an opening and globalizing economy, historical experience and

peers within China offer few tightly predictive examples, so local administrators rely on foreign partners (investors, government or experts) to provide ideas for policy (Chien and Ho, 2011). In city transport, this manifests as parallel experiments with a wide variety of transport policy instruments employed elsewhere in the world.¹

4.1.1 National-level policy: promotion of NEVs and energy security

China's central government historically managed the automotive manufacturing industry directly, setting up state-owned enterprises (SOEs) in the sector, and later promoting their cooperation with foreign partners through international joint venture (IJV) arrangements. Objectives of IJV promotion include supporting domestic manufacturing but also transfer of intellectual property and development of innovation capacity that increases the competitiveness of the domestic participants (Nam, 2010, 2011).

As early as the 9-FYP (1995–2000), the promotion of NEVs has been a feature of central government policy with respect to vehicles, encompassing promotion of HEVs, PHEVs, BEVs and fuel cell vehicles (Gong et al., 2012).² Objectives included avoiding local air pollutions and “energy saving” (reduction in petroleum demand). Approaches used included funding research and development; setting targets for adoption; fleet pilots specifically sited in second-tier cities, and a variety of generous subsidies to businesses and households purchasing vehicles.

Commentators have long speculated on the supply side of the Chinese energy security concerns (Downs, 2004), but note that the central government seemed somewhat surprised by the recent rapid growth (Downs, 2006), which is projected here to continue unless stringent policy is enacted. Management of domestic demand as a means to reduce exposure to import risks remains a major challenge for the government (Daojiong, 2006), but one area of response has been the promulgation of fuel economy standards (FES) for new vehicles, modelled on the United States' Corporate Average Fuel Economy (CAFE) system, with a parallel objective of encouraging adoption of

¹As experiments, these have had mixed success; for instance, Shanghai has tolled some arterial roads and highways, yet with limited impact on congestion (Wang et al., 2008).

²Although the NEV acronym was not used until 2007.

more advanced, efficient NEV technologies (Hu et al., 2010). Karplus et al. (2012a) highlights that, compared to economy-wide climate policy of the type considered here, requiring emissions reductions to occur in the own-supplied transport sector selects a non-marginal, high cost means of reducing overall emissions.

The identified effects of policy on the transport sector show that policymakers can expect refined oil demand, in particular, to continue to rise without policy, or with energy-intensity style targets which do not impose strict caps on energy use or greenhouse gas emissions. Refined oil use accompanies strong growth in automotive fleets and therefore sales, which would continue to help support the domestic auto industry; but the policy conditions for large-scale adoption of PHEVs are not created without the influence of high fuel costs under a climate stabilization policy, and the limitation of refined oil demand—and therefore imports, and energy security risks—is not solely due to NEV adoption, but also reduced driving.

4.1.2 Policy in urban areas: vehicle ownership, use and public transport

In addition to entrepreneurialism leading to heterogeneous policies in cities (Chien and Ho, 2011), it affects the policy objectives and agenda of municipal governments. In an inherently conservative bureaucracy without political or electoral mechanisms incentivizing quick response to public concerns, the main externalities of high vehicle ownership and use—urban air pollution and road congestion—appear to be addressed strongly because they directly impact the middle class to which many bureaucrats belong (Seligsohn et al., 2010; Seligsohn, 2012). For the same reason, although walking, cycling, and two-wheel electric vehicles are retain a non-trivial mode share in Chinese cities (Peng, 2004; Weinert et al., 2007, 2008), their regulation appears to be a less pressing policy matter; on the other hand, strong purchased transport demand—identified here as continuing to grow rapidly through mid-century even under stringent policy—is being continually addressed through rapid build-out of public transit systems both within and between cities.

Although the policies studied in the foregoing chapters are economy-wide and national-level policies, they show effects of limiting vehicle ownership, which municipal governments have been attempting to do directly. Policies on both urban vehicle ownership and use and the support of purchased travel through public transport infrastructure are discussed separately in the following subsections.

4.1.2.1 Municipal policies affecting vehicle ownership and use

Two categories of municipal policies constrain vehicle transport: those which affect the ownership of vehicles, and those affecting their use. To affect ownership, Shanghai has conducted license plate auctions for over a decade which restrict the number of new cars put on the road to about 110,000 per year (Feng and Ma, 2010; Luo et al., 2011). A limited number of new plates are licensed each month; prices can reach as much as CNY 60,000 (Hao et al., 2011).³ Beyond limiting the number of vehicles, the plate auction has other effects; vehicles sold in Shanghai tend toward larger, more expensive models preferred by the richer citizens who can afford to win a plate at auction. This policy induces some leakage as owners register vehicles instead in surrounding provinces without auctions (Luo et al., 2011); however, these vehicles are barred from using the main highways to enter the city during rush hours.

Beijing, in contrast, has recently adopted a lottery system in which no payments are collected. Waits are long, yet the city still adds nearly 300,000 cars per year to its population (Hao et al., 2011). In an explicit attempt to combine features of the Beijing and Shanghai approaches, Guangzhou has announced plans for a hybrid, auction-and-lottery system (Caixiong, 2012). Hao et al. (2011) give trajectories of income and vehicle ownership levels for Beijing, Shanghai and the provinces, and also suggest that, in the absence of policy, Shanghai's ownership level may have risen at the same rate as Beijing's in the period 2001–2010.

Concerning household vehicle use, driving in Beijing was heavily but temporarily restricted during the 2008 Summer Olympics, with measurable effects on quantities

³Much greater, for instance, than the price of the Chery QQ3 or Geely Meiri minicars, which cost about CNY 30,000 each (Xi et al., 2009).

of emissions and air quality (Wang et al., 2010; Wu et al., 2011). A vestige of this policy remains, with one fifth of vehicles nominally barred from the city's ring roads each weekday; however, this is not viewed as being strongly enforced.⁴ Anas et al. (2009) show that while fuel taxes and congestion charging may be expected to have some effect on vehicle use, ultimately this category of policy is less of a determinant of congestion than the difference in ownership. Beijing has also introduced regional standards for pollutant levels in fuels as a means of addressing air pollution without restricting ownership or driving (Xin, 2012); and while other cities have studied restrictions on driving, few have adopted them (Yin et al., 2011; Hao et al., 2011; Suen, 2012).

Within the restrictions on ownership, however, are municipal exceptions and subsidies for NEVs, some of which are additional to central government subsidies; these are undertaken because municipal governments believe that non-gasoline vehicles will contribute fewer emissions to local air pollution problems that accompany congestion. However, in the present modelling results, adoption of high-cost NEVs is significant only under climate stabilization policy which increases the cost of other driving and fuel use (Figure 3-3). Also, while reducing refined oil use, PHEVs require charging infrastructure and electricity. Transport emissions in Beijing are a major contributor to summer air pollution, but winter air quality problems also arise from nearby coal-fired electricity generation (Sun et al., 2004). If these plants are to be used year round—or, indeed, if additional plants are built—to supply electricity to private transport, this problem would become persistent and more difficult to address. Similarly, while biodiesel and other biofuels may produce fewer and less toxic emissions (Morris et al., 2003), fuel standards cannot eliminate these emissions entirely, and will not address congestion goals.

Generally, when municipal ownership policies are contrasted to the NEV promotion goals of policies of central government, these have almost directly opposite aims. A direct effect of Guangzhou- and Shanghai-style restrictions in constraining ownership is to lower sales of new vehicles; since the cities are also home to China's wealthiest

⁴Personal correspondence.

citizens, they are being discouraged from purchases which would otherwise serve to support economic rebalancing for the “pillar” automotive industry (Steinfeld, 2008). The central government has commented when use of revenue from the auctions appeared to be allocated to non-transport activities, and more recently has suggested that ownership restrictions are harmful to the auto industry, but to date has not intervened against auctions (Jing, 2012; Zeng, 2012). If the central government chooses to address energy intensity and emissions in non-transport sectors, and pursue energy security through foreign policy rather than domestic demand management,⁵ own-supplied household transport demand will likely continue to increase, and cities may elect to pursue congestion and local air pollution goals through continuation of current policies, exacerbating this conflict.

4.1.2.2 Public transit infrastructure

To meet rising transport demand, China’s cities have also invested heavily in their public transit networks, which already include the first- and fourth-largest networks in the world; they are further planning aggressive expansions of subway systems at great cost (Table 4-1).

The large and expanding track length, differences in fare structure, and feeder networks of bus and regional rail services affect the ridership levels of these systems (Hu et al., 2010), which remain high despite passenger congestion having a negative effect on perceived comfort of public transport.⁶ In Shanghai, urban railways take travellers unable to afford auctioned license plates and vehicles, sup-

City	Track distance [km]	
	2012	Planned @ year
Shanghai	425	877 @ 2020
Beijing	372	1050 @ 2020
Guangzhou	236	677 @ 2020
Shenzhen	178	348 @ 2016
Tianjin	109	255 @ 2016

Table 4-1: Public transit systems in China, by length (Schwandl, 2012; Guangzhou Urban Planning Committee, 2010; Zhang and Yang, 2012; Xin et al., 2012).

⁵The policy constraints modelled here are not focused on energy security *per se*, so the EPPA results are consistent with a scenario in which the government does not act to curtail refined oil use for energy security reasons.

⁶Personal correspondence.

plying one third of passenger travel demand (National Bureau of Statistics of China, 2012).

While early lines were constructed entirely by state-owned entities (SOEs), cities have since used a variety of public-private partnership (P3) structures to construct and operate transit projects (de Jong et al., 2008), from one-time, single-line arrangements with one outside partner, to a structure now standardized for Shanghai in which at least four separate aspects of rail extension are handled by separate government or private partners (Yuan and Lou, 2011; Loo and Li, 2006). Growth in future demand for purchased transport services that—as identified here—continues even with limitation of overall and own-supplied demand under policy, will affect expected ridership and revenues, and in turn local governments' ability to guarantee returns and leverage private investment.

Further, Schäfer and Victor (2000) note that the travel money budget in Japan is stable at only 7 percent, due to the Japanese government's historic strong support of the *Shinkansen* high-speed rail network, among other factors. If China's central government wishes to pursue energy or emissions targets which are more severe than the current, intensity-based policy and set economy-wide caps on emissions, much higher household expenditures for transport, as projected in Figure 3-12, are one result. However, China has also invested heavily in development of a large high-speed rail network (Campos and de Rus, 2009), so the experience of Japan suggests that providing long distance travel through non-vehicle modes is one option that may be considered to reduce restrictions on mobility—although China's greater area will affect whether such approaches are economical.

4.2 Limitations and opportunities for extension

This work offers a number of opportunities for extension. As noted, energy security is a major national policy concern arising from increased refined oil use associated with rising demand for household transport. Projections of total demand under policy scenarios such as those in Chapter 3 can be one input to a framework that models

global oil markets, and can be useful for understanding long-term energy security risks might change with reduced demand.

Returning to Figure 1-1, inter-provincial differences in wealth and vehicle ownership are large, and as just noted the wealthiest cities of Beijing and Shanghai have followed very different paths according to their individual policy choices. Even the central government, in explicitly assigning provincial sub-targets under the 12-FYP energy intensity goal, makes explicit reference to differentiated effort between rich and poor provinces in Zhang et al. (2012)—the Kyoto principle on a sub-national scale. As urbanization continues, the gap between national aggregate household transport indicators and, for instance, the level of motorization in the poorest provinces may widen. Projections, analysis or policymaking based on national averages, or a static disaggregation of national figures, may then suffer from the “flaw of averages” (de Neufville and Scholtes, 2011).

This challenge points to the importance of extending the present analysis into a CGE model with a more disaggregated representation of China’s economy, to allow representation of significant provincial, regional, or—at the very least—urban-rural differences which may be obscured in EPPA. The China Regional Energy & Emissions Model (C-REM) developed by Zhang et al. (2012) as part of the Tsinghua-MIT China Energy & Climate Project is one candidate for this extension. C-REM mirrors important features of EPPA while incorporating a sophisticated integration of disparate statistical sources on Chinese energy, emissions and domestic trade.

To capture even richer regional detail, as well as allow for separate representation of various types of small vehicles popular in Chinese cities, a further enhancement would be to perform a top-down/bottom-up coupling of EPPA or C-REM to a transport model calibrated on a per-region basis. This would allow representing the transport response to urban growth trends that may differ from place to place (Nam and Reilly, 2012). Schäfer et al. (2009) demonstrate the value of this sort of linkage in transport projection and policy analysis, using EPPA and a MARKAL-based transport model; in the Chinese case a discrete mode choice model might be possible, as data are available (Jing, 2012).

4.3 Conclusions

In this analysis, I applied an existing computable general equilibrium model that incorporates technology detail and options for substitution in the household transport sector, to the study of future demand for purchased and vehicle transport in the rapidly-growing Chinese market. I adapted the model to match China's observed process of motorization through the present, and further developed three scenarios of future growth in both total transport demand and the shares given to purchased and own-supplied modes. With this updated model, I applied two economy-wide policy scenarios, one simulating the extension of energy intensity measures currently in place in China, and one related to a global greenhouse gas stabilization strategy.

Comparing the outcomes with a no-policy case, I find that adoption of vehicle transport demand leads to refined oil use associated with transport growing by a factor of six to approach coal's share of primary energy by mid-century. Ownership passes 350 vehicles per 1000 capita, and total private vehicle stock reaches nearly 500 million, with transport taking 10 to 15 percent of household budgets—levels comparable to developed countries with higher motorization.

I find, further, that these trends are only modestly affected by policy continuing present energy-intensity goals, with small decreases in travel activity and energy intensity of vehicles combining for a reduction in refined oil use; such a policy has modest cost and affects household transport less than other sectors. In contrast, my results show that a stringent emissions cap associated with GHG stabilization has large impacts on vehicle efficiency, limits vehicle ownership and general travel activity levels as it drives household transport budget share to levels between 19 and 24 percent. Because of the rapid growth in transport-related refined oil demand without policy, the transport sector plays a greater role in climate stabilization relative to previous analysis for the United States. Of a smaller vehicle fleet (250 million total, or 200 per 1000 capita), sixteen percent is composed of new energy vehicles, and total refined oil use increases less than 3 times from its 2010 level. However, these effects come with a reduction in total primary energy as the policy is introduced, and large costs

economy-wide.

These results are salient to passenger transport-related policy objectives of China's central and large urban governments, some of which I elucidate. Chinese policymakers can recognize that the industrial and quality-of-life benefits of strong vehicle sales are accompanied by large increases in emissions and oil imports, even with advanced technologies available. A strong climate policy will likely be needed to have the vehicle ownership- and use-limiting effects desired to reduce congestion and local air pollution in cities, or the management of demand for oil imports, but involves acute tradeoffs in both household transport and overall consumption. This work lays the foundation for future work focused on further methodological development and the impact of a wide range of transport focused policies at the regional level in China and on international energy markets.

Appendix A

Calculation of input shares to household transport

Listing A-1: Calibration of input shares to own-supplied household transport.

```
from collections import defaultdict
from os.path import join
import sys

import numpy as np
from scipy.constants import mile

# Constants for EPPA regions
from EPPA import *

DATA_DIR = '/net/fs04/fs02-d0/cecp/data/' # Location for data files
YEAR = '2004' # EPPA5 initial period
opts = {'delimiter': '\t', 'dtype': None} # Common options for reading CSV

data = defaultdict(dict) # storage for data

np.set_printoptions(precision=4)

def region_data(var, region, report_missing=False):
    result = []
    missing = []
    for country in rc[region]:
        if country in data[var] and not np.isnan(data[var][country]):
            result.append(data[var][country])
```

```

        else:
            missing.append(country)
    if report_missing:
        print('{}: No {} data for {}'.format(region, var, ' '.join(sorted(
            missing))))
    return result

def lookup(var, region, function=sum):
    if r in country_regions:
        try:
            return data[var][code[r]]
        except KeyError as e:
            print(e)
            return 0
    else:
        return function(region_data(var, code[r], True))

## Load the countries-to-EPPA regions mapping
rc = defaultdict(list)
for country, region in np.genfromtxt(join(DATA_DIR, 'countries.csv'),
                                     usecols=(0,2), **opts):
    rc[region.decode()].append(country.decode())
del rc['EPPA5 region']

## Load parts of the HTRN database
DATA_DIR = join(DATA_DIR, 'htrn')
opts.update({'names': True, 'skip_header': 'comment'})

# Global Market Information Database. Quantities:
#
# * DIES -- Diesel/gas oil consumption 6[10 kg]
# * EXP-0 -- Consumer expenditure on operation of personal transport equipment
# 6 [10 USD]
# * EXP-T -- Consumer expenditure on transport services 6[10 USD]
# * EXP-V -- Consumer expenditure on purchase of cars, motorcycles, other
# vehicles 6[10 USD]
# * MGAS -- Motor gasoline consumption 6[10 kg]
# * VDT -- Car traffic volume 6[10 .carkm]
# * VDT-V -- Average annual distance travelled by car [km]
#
for row in np.genfromtxt(join(DATA_DIR, 'gmid.csv'), **opts):
    key = 'GMID {}'.format(row['Quantity'].decode())
    data[key][row['Country'].decode()] = row[YEAR]

```

```

# International Road Federation / World Road Statistics. Quantities:
#
# * REG-N -- New car registrations [0]
# * VDT -- Vehicle distance travelled per year 6[10 km]
# * VDT-PCAR -- Passenger car distance travelled per year 6[10 km]
# * VDT-V -- Vehicle distance travelled per vehicle, per year [km]
#
for row in np.genfromtxt(join(DATA_DIR, 'irf.csv'), **opts):
    key = 'IRF {}'.format(row['Quantity'].decode())
    data[key][row['Country'].decode()] = row[YEAR]

# Miscellaneous data by region. Quantities:
#
# * VDT -- Vehicle distance travelled 12[10 miles]
# * ACA -- Total consumption 10[10 USD @ 2004]
# * Share -- Transport as a share of total consumption [0]
# * Fuel -- Total expenditure on transport fuel 10[10 USD @ 2004], GTAP
#
misc = np.genfromtxt(join(DATA_DIR, 'misc_region.csv'), **opts)

## Preprocess some data
exp_v = np.zeros([16]) # expenditure on vehicles
reg = np.zeros([16]) # registrations
vdt_v = np.zeros([16]) # distance travelled per vehicle [km]
for r in range(16):
    exp_v[r] = lookup('GMID EXP-V', r)
    reg[r] = lookup('IRF REG-N', r)
    vdt_v[r] = lookup('GMID VDT-V', r, np.mean) / ( mile / 1000.)

# Adjustments in VDT per vehicle:
print('\nVDT per vehicle adjustments:')
print(' AFR from {} to 8000'.format(vdt_v[AFR]))
vdt_v[AFR] = 4000
print(' CHN from {} to '.format(vdt_v[CHN]), end='')
vdt_v[CHN] = 18200 * 1000 / 1609
print('{}'.format(vdt_v[CHN]))
for r in (BRA, IND, MEX, RUS, ASI, LAM, REA, ROE):
    print(' {} from {} to 8000'.format(code[r], vdt_v[r]))
    vdt_v[r] = 8000

## Calculations
# Capital recovery charge rate
crc = 0.09 * np.ones([16])

```

```

# Levelized cost per distance
lcpd = (misc[:]['ACA'] * misc[:]['Share'] * 10**10) / (misc[:]['VDT'] * 10**12)
# fuel cost per distance = tro
tro = (misc[:]['Fuel'] * 10**10) / (misc[:]['VDT'] * 10**12)

# cost of new vehicles = expenditure on vehicles / # of vehicles registered
nvc = (exp_v * 10**6) / (reg * 10**3)
# corrections:
print('\nNew vehicle cost adjustments:')
# Adjust USA, CAN to reflect share of light trucks
print(' USA from {} to {}'.format(nvc[USA], nvc[USA]/2.))
nvc[USA] /= 2.
print(' CAN from {} to {}'.format(nvc[CAN], nvc[CAN]/1.5))
nvc[CAN] /= 1.5
print(' AFR {}, REA {} \n to IND {}'.format(nvc[AFR], nvc[REA], nvc[IND]))
nvc[AFR] = nvc[IND]
nvc[REA] = nvc[IND]
print(' ASI {} \ LAM {}, ROE {} to BRA {}'.format(nvc[ASI], nvc[LAM],
                                                    nvc[ROE], nvc[BRA]))
nvc[ASI] = nvc[BRA]
nvc[LAM] = nvc[BRA]
nvc[ROE] = nvc[BRA]
print(' MES from {} to RUS {}'.format(nvc[MES], nvc[RUS]))
nvc[MES] = nvc[RUS]

# Powertrain industrial
ptoi = (0.2 * nvc) * crc / vdt_v
# Total other industrial
toi = nvc * crc / vdt_v
# Services (residual)
tse = lcpd - tro - toi - ptoi

# Fractions of total
tse_frac = tse / lcpd
toi_frac = toi / lcpd
ptoi_frac = ptoi / lcpd
tro_frac = tro / lcpd

## Generate output
with open('htrn-shares.csv', 'wb') as f:
    f.write(bytes('\t'.join(code), 'utf-8'))
    f.write(b'\n')
    np.savetxt(f, np.vstack((toi_frac, tse_frac, tro_frac, ptoi_frac)),
               delimiter='\t', fmt='%.4g')

```

Appendix B

Map of China



Figure B-1: Map of Chinese provinces, provincial capitals and directly-governed municipalities. Adapted from the Wikimedia Commons file “China administrative PRC”.

Appendix C

Publications of Chinese transport statistics

The *China Statistical Yearbook* is the flagship publication of the National Bureau of Statistics of China. While these annual documents and accompanying data files contain some glossary information on the contents of the tables, the NBSC does not publish enough information about its data collection methodology to allow nuanced critique or correction by interested third parties. In part this is because of historically limited resources; with low capacity within the NBSC itself to dictate data collection practices, it is reliant on per-sector provincial government agencies to furnish data, and these can have mixed quality for a variety of reasons (Sinton, 2001).

As well, despite the availability of provincial yearbooks containing a variety of less aggregated transport information not present in the national accounts, these are not typically translated for a foreign audience, and so usually elude inclusion into English-language data bases. One example is Sichuan Department of Transportation (2011). Fourin, Inc. (2011), a Japanese firm, also publishes a *China Automotive Industry Yearbook* based on data obtained directly from manufacturers, but as a private effort this is, again, not open to methodological scrutiny.

Close perusal of the data from NBSC itself show that the same points will change from year to year, and at several points earlier data has been dropped from transport series and not reintroduced, possibly indicating low quality and a lack of basis for

correction to the current standard. For instance, the 2002 Yearbook omits previously-published figures for passenger travel volume from 1952 through 1975, a period which includes years of the Cultural Revolution (1966–1976) (National Bureau of Statistics of China, 2002, 2003).

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