The Future Energy and GHG Emissions Impact of Alternative Personal Transportation Pathways in China

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Abstract

A major uncertainty in future energy and greenhouse gas (GHG) emissions projections for China is the evolution of demand for personal transportation modes. This paper explores the implications of two broadly divergent personal transportation scenarios: one favouring personal vehicles, and another emphasizing local public transit, rail and aviation as substitute for vehicle travel. The scenarios are broadly defined based on observed divergent personal transportation patterns and existing forecasts. The analysis compares primary energy use and GHG emissions in China under each pathway, both in the absence and presence of climate policy, and identifies conditions that would favor the choice of one pathway over another.

1 Introduction

China's future energy use and associated greenhouse gas (GHG) growth trajectory will play a decisive role in global climate change outcomes over the next century. Energy use and GHG emissions have increased over the past three decades, while energy intensity—the ratio of energy use to economic output—has fluctuated over time. While China has announced energy and carbon intensity targets through 2020, meeting targets in 2020 and beyond depends on technology choices and behavioral responses by consumers and firms across the economy, and also on government policies designed to influence these. How these choices and responses are likely to evolve with continued increases in disposable income is a major source of uncertainty in future projections of energy use and GHG emissions.

Personal mobility today is a major energy-consuming activity that tends to increase as GDP rises, although the relationship is not uniform and has been shown to depend on a range of factors such as population density or degree of urbanization (Dargay et al., 2007). In recent years, demand for vehicle ownership and use, as well as purchased modes of travel, has increased rapidly. Today, the transport sector accounts for around 8% of total energy use in China. Despite its small share, petroleum requirements of the existing vehicle fleet have raised policy concerns about reliance on imported resources

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and tailpipe contributions to poor air quality in urban areas. Policymakers in China are discussing the appropriate combination of support for new energy vehicles and purchased alternatives to vehicle transport in order to address climate, energy, and air quality goals. This analysis attempts to inform policy discussions by identifying the energy and GHG impacts of scenarios that assume different levels of reliance on purchased modes relative to privately-owned vehicles.

This paper is organized as follows. In Section 2, a review of recent literature discusses forecasts of China's personal mobility (including vehicle) demand in the context of established methods used to generate them, and describes the contribution of this analysis. Section 3 introduces the EPPA model, the development of three scenarios for own-supplied and purchased demand (measured in passenger-kilometres travelled, or PKT) growth, and the method for implementing these scenarios in the model. Section 4 describes the energy use and GHG emissions impacts in each of scenarios in the presence and absence of a CO_2-equivalent constraint, which is implemented as an economy-wide cap-and-trade system. Sections5 and 6 offer some directions for future work and some preliminary conclusions.

2 Review of literature

The relationship between rising personal mobility demand and energy and emissions outcomes has been extensively studied in previous global, regional, national, and sub-national forecasting exercises. These studies span the transport demand modeling and energy economics literatures, and employ a wide range of methods and techniques. Studies vary in the number of different demand drivers they consider. Schafer and Victor (2000) employ an empirically-estimated travel-time budget and travel-money budget (as a fraction of income) to forecast demand for different modes over time, modeling a shift to ever-faster modes as income increases. Other models focus on vehicle ownership and include additional factors such as urbanization and population density (Dargay et al., 2007) or account explicitly for changes in the household transport expenditures and demand as disposable incomes rise (Meyer et al., 2007).

Studies of China's future transport energy and CO_2 emissions begin with projections of demand for vehicle-kilometers traveled or passenger-kilometers traveled. Most China-related transport studies to date have focused on demand for vehicles and vehicle travel (Dargay et al., 2007; Wang et al., 2011, 2006; Han and Hayashi, 2008; Huo et al., 2011b,a; A.T. Kearney, 2011; Barclays Capital, 2011), while less attention has been focused on demand for purchased modes. As shown in Figure 1, projections of vehicle stock vary widely. From the early 2000s through 2011 most studies underestimated the rate of light-duty or privately-owned vehicle fleet growth; projecting a 2010 vehicle population of 47-54 million against an actual figure of 78 million (Wang et al., 2011; China National Bureau of Statistics, 2010). 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 kilometers-traveled per vehicle, leading to a wide range of projections of refined fuel demand and CO_2 emissions.

Understanding how China's vehicle fleet will grow in the future requires understanding regional disparities in travel demand patterns. As shown in Figure 2, there is not a tight correspondence between annual per capita income and levels of vehicle ownership in China across its provinces—Beijing and Shanghai, the two provinces with the highest per-capita incomes—had very different levels of vehicle ownership in 2009. The older Shanghai license plate auction policy has reduced ownership there relative to Beijing, but other, quota-free provinces display similar low income elasticities of demand: Hao et al. (2011). As disposable income grows, whether the less developed provinces follow a trajectory closer to Beijing or to Shanghai will—together with region-specific demands for travel—determine energy and environmental impact in the nation as a whole. Another critical source of uncertainty is

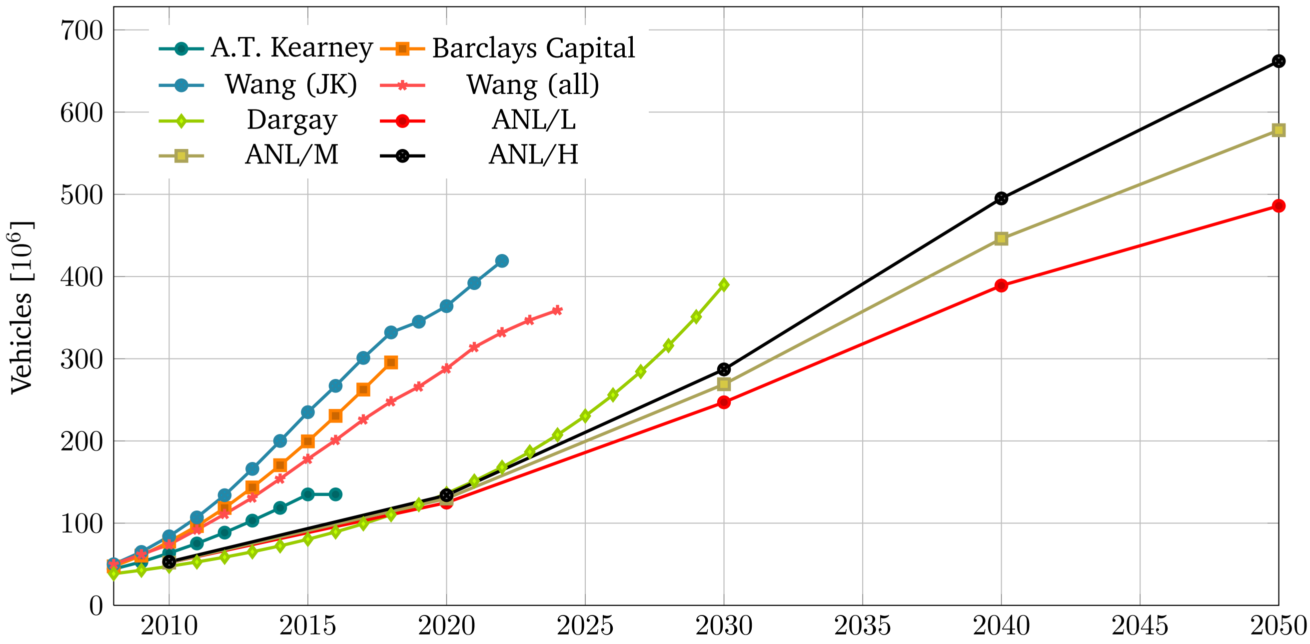

Figure 1 – Projected growth of total vehicles in use (stock) through 2050 by various studies. "Wang (JK)" and "(all)" refer to the projections from Wang et al. (2011) using the Japan/Korea and all-countries panels, respectively. The Argonne National Laboratory (ANL) 'L'ow-, 'M'edium- and 'H'igh-growth projections are from Wang et al. (2006).

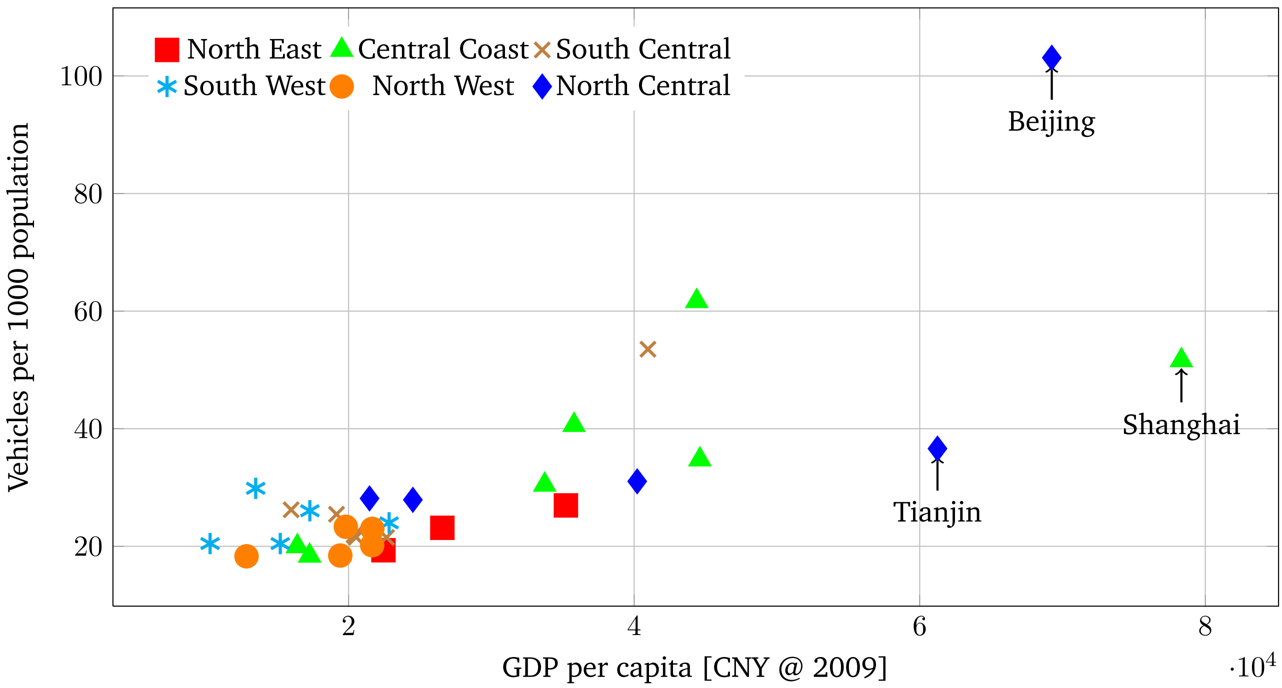

Figure 2 – Relationship between annual per capita income and private vehicle ownership per 1,000 capita. Each data point corresponds to a different province in China (China National Bureau of Statistics, 2010).

consumers' willingness and ability to substitute between purchased modes and private vehicle ownership.

The main contribution of this analysis is to understand the implications of meeting rising travel demand through different modes in a framework that captures inter-modal competition for transportation fuels. Most forecasts of transportation energy use in China have been performed with bottom-up vehicle fleet and energy accounting models that take vehicle stock, kilometers-traveled, vehicle fuel economy and powertrain technology, and fuel prices (if used) as given. A few studies of the impacts of policies on transportation energy use have been conducted using energy-economic models with broad sectoral coverage (Zhou et al., 2011). Schafer and Jacoby (2006) incorporate price feedbacks to demand and capture endogenously the impact of climate policy on mode shares and technology choice using a coupled top-down bottom-up modeling approach. Here we use a technology-rich top-down model to simulate exogenously imposed trajectories for the shares of PKT provided by purchased modes and privately-owned vehicles. This economy-wide energy-economic framework further allows us to perform an initial assessment of the impact of a carbon constraint on energy use and CO_2 emissions outcomes under alternative mode share scenarios.

3 Methodology

3.1 The MIT Emissions Prediction & Policy Analysis (EPPA) model

The model used in this analysis is a specialized version of the MIT Emissions Prediction and Policy Analysis (EPPA) model that includes a technology-rich representation of the passenger vehicle transport sector and its substitution with purchased modes, represented as the aggregate of aviation, long- and short-distance rail, marine and public road transport. The EPPA model is a recursive-dynamic general equilibrium model of the world economy developed by the Joint Program on the Science and Policy of Global Change at the Massachusetts Institute of Technology (Paltsev et al. 2005). The EPPA model is built using the Global Trade Analysis Project (GTAP) dataset (Hertel (1997); Dimaranan and McDougall (2002)). For use in the EPPA model, the GTAP dataset is aggregated into 16 regions and 24 sectors with several advanced technology sectors that are not explicitly represented in the GTAP data. Additional data for greenhouse gases (carbon dioxide, CO_2; methane, CH_4; nitrous oxide, N_2O; hydrofluorocarbons, HFCs; perfluorocarbons, PFCs; and sulphur hexafluoride, SF_6) are based on United States Environmental Protection Agency inventory data and projects.

Several features were incorporated into the EPPA model to explicitly represent passenger vehicle transport sector detail. These features include an empirically-based parameterization of the relationship between income growth and demand for vehicle-miles traveled, a representation of fleet turnover, and opportunities for fuel use and emissions abatement. These model developments, which constitute the EPPA5-HTRN version of the model, are described in detail in Karplus (2011).

The present work contains a renewed calibration of the private vehicle sectors, with special attention paid to China, using up-to-date data from sources including the IEA World Energy Balances (International Energy Agency, 2010), Euromonitor GMID (Euromonitor, 2011), and the World Road Statistics databases (International Road Federation, 2010).

3.2 Scenarios of travel demand growth

Surveying the projections for transport indicators illustrated in Figure 1, we observe that they differ greatly, are generated using a variety of methods, and anticipate long-term, peak vehicle ownership in China corresponding to various other countries—from Japan on the low side, to the United States on the high side. We adopt no view of the relative quality of the forecasts, nor the implicit predictions about how long and to what extent current, rapid growth can be sustained. Instead, we develop low, medium, and high-ownership scenarios that together bracket available forecasts and provide a middle or median projection; recognizing also that we are not considering other scenarios that may be relevant. The method used is described below.

The constant elasticity of substitution (CES) utility of the EPPA representative household results in demand shares for commodities that tend to be preserved even as total consumption grows. In the case of transport, this means that expenditure on each of purchased and private vehicle transport grows at the same rate as GDP. China's recent experience of rapidly demand growth is remarkable because, as highlighted in Wang et al. (2011) and elsewhere, it has held at several points above the rate of GDP growth for several years. This indicates a rising share of expenditure for transport.

To recreate this trend and its possible continuation in EPPA, a strategy of share-forcing is used. In all scenarios, the total demand for travel is scaled upwards until the most recent model period (2010), so that outputs for private transport match available data. A final adjustment in the 2010-2015 period is different among our scenarios, and produces the three trajectories in demand growth.

The scenarios also encode the abovementioned insight from Schafer and Victor (2000) that the most rapid growth in travel demand will come with a preference for faster modes (personal vehicles) over slower ones. Because current purchased transport in China is composed mostly of lower-speed modes, we model this behaviour by depressing the share of purchased transport in total demand. This effect is most pronounced in the high vehicle ownership scenario.

Finally, in all scenarios the income share of transport in the overall household budget is attenuated in the later periods when per-capita vehicle ownership approaches the current European level of about 600 vehicles per thousand population.

Model runs for all three scenarios were conducted both with and without an example climate policy. We use a cap-and-trade example wherein aggressive global quotas on emissions produce end-of-century greenhouse gas concentration of roughly 550 parts per million CO_2-equivalent. The policy becomes active in 2020 and proceeds through 50% of reference-case emissions in 2050, where our model runs end. The starting date for this policy is the earliest conceivable given the state of current international negotiations. One notable implication of a global, as opposed to national, policy is that decreased demand for petroleum worldwide also results in a lower fuel price experienced in China.

4 Results

Results are presented in Figures 3 through 9 and described below.

Figure 3 gives total primary energy in the reference (no policy) and policy cases, by source. The inital reduction for coal, China's largest fossil fuel source, is dramatic in both the short- and long-term, which highlights that such an aggressive carbon policy in China is unrealistic due to sheer cost. However, the consumption of transport fuels derived from oil (in blue) is the main indicator of the different transport scenarios; and shows significant but more modest reductions that reflect a resilience of demand. The effect of policy here is an initial reduction in oil consumption, followed by a very gradual growth through 2030 (reaching 38-46% of reference case demand) and an equally shallow decline to 21-24% of reference demand; this is also visible in Figure 4. The slow decline is mostly driven by a corresponding trend in the U.N. population projections underlying the model. Less visible in the figure is the increase in biofuels, which see no use in the reference case, but peak at 2.3-3.1 EJ (7-8% of combined oil plus biofuel demand) in the policy scenarios.

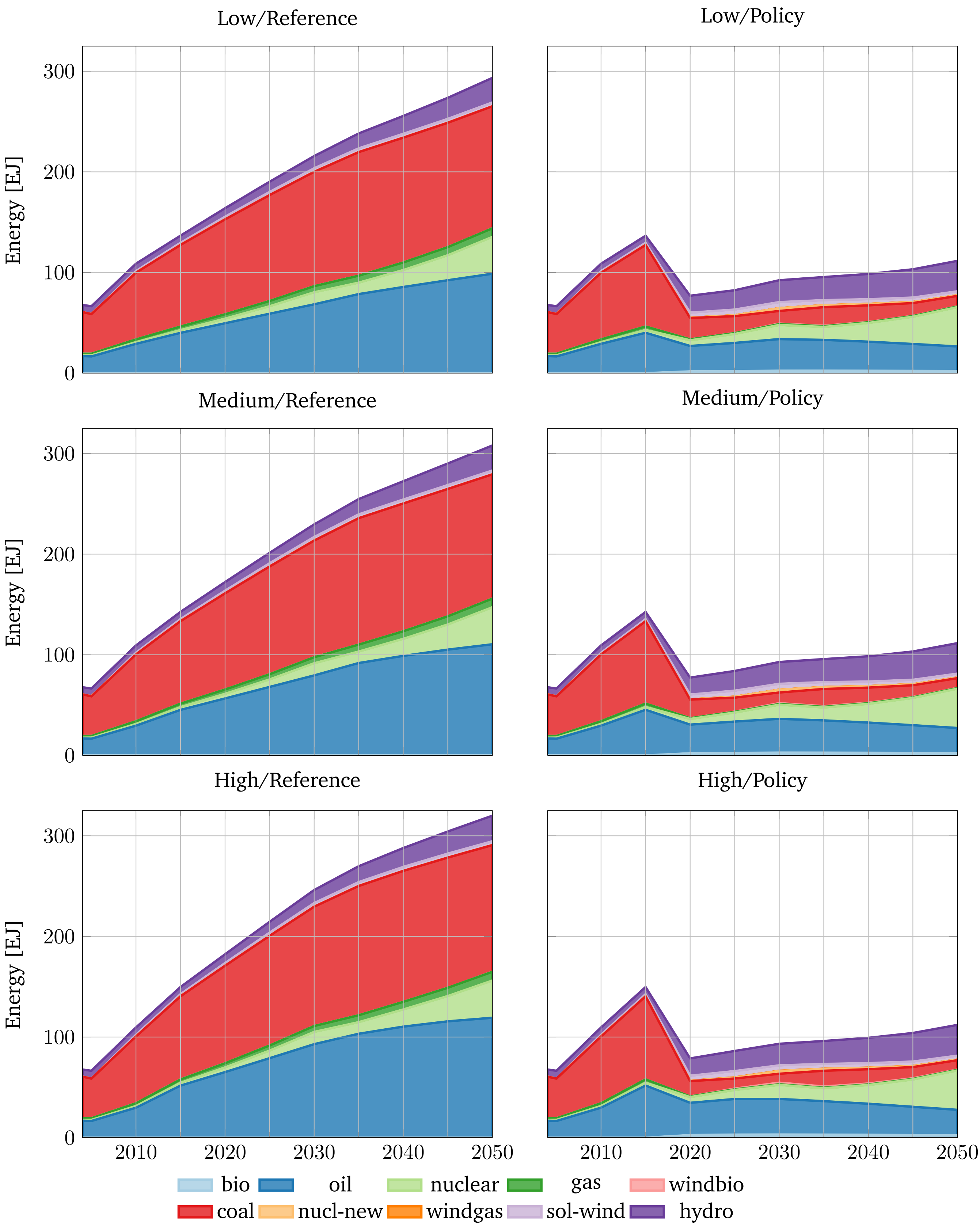

Figure 3 – Total Chinese primary energy by source and year for all scenarios and the presence/absence of policy.

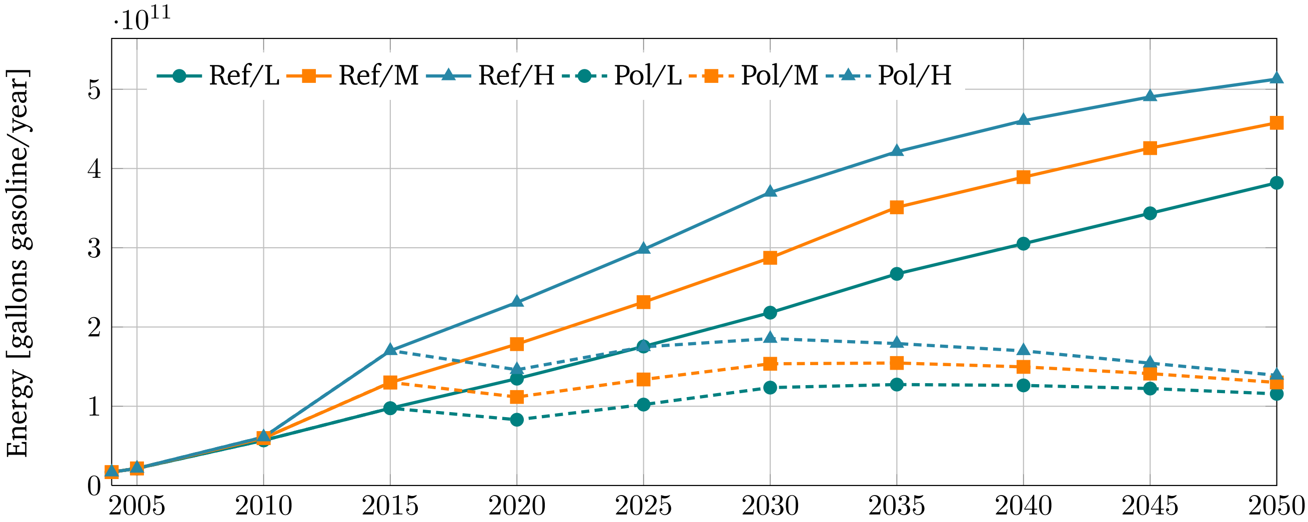

Figure 4 – Refined oil use in household transportation, by year.

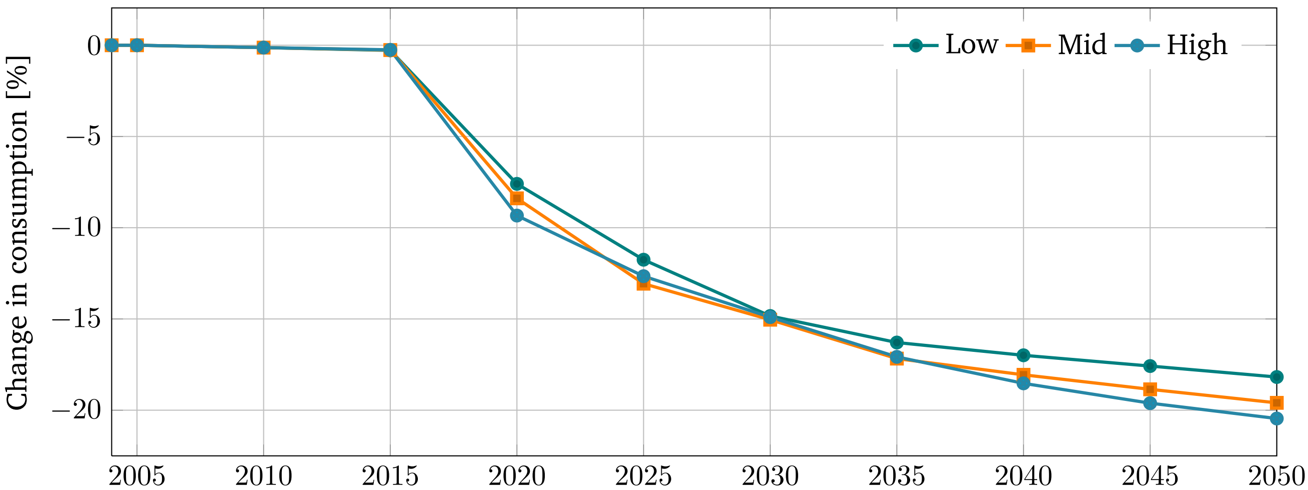

Figure 5 – Change in consumption due to policy relative to reference case, by year.

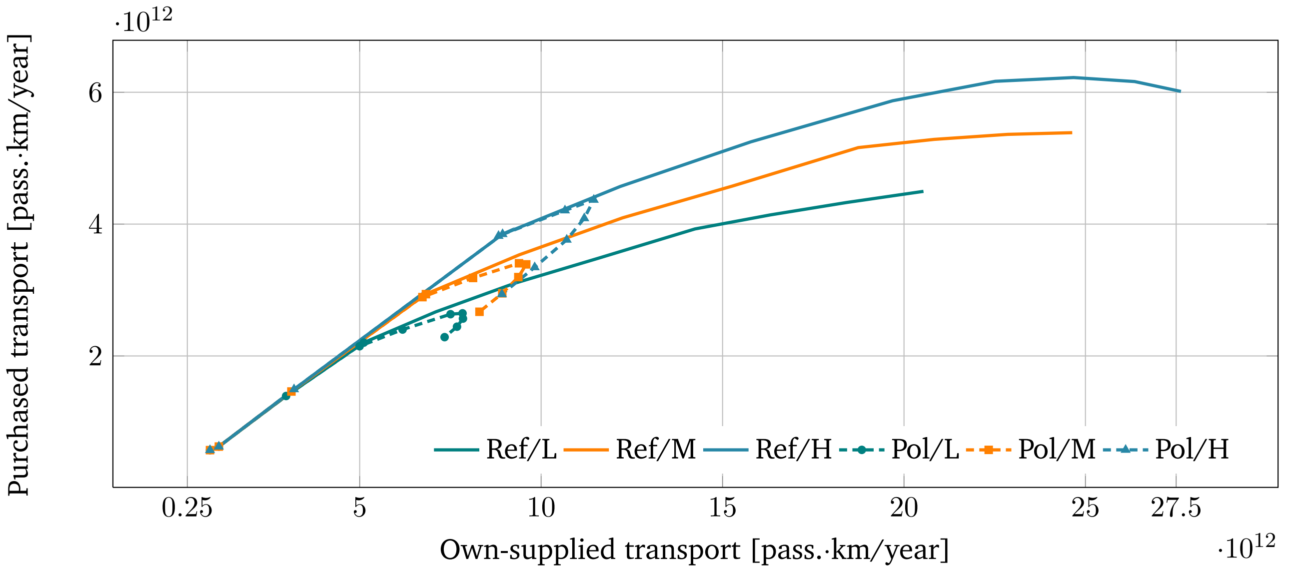

Figure 6 – Trajectories of purchased and own-supplied transport, by scenario.

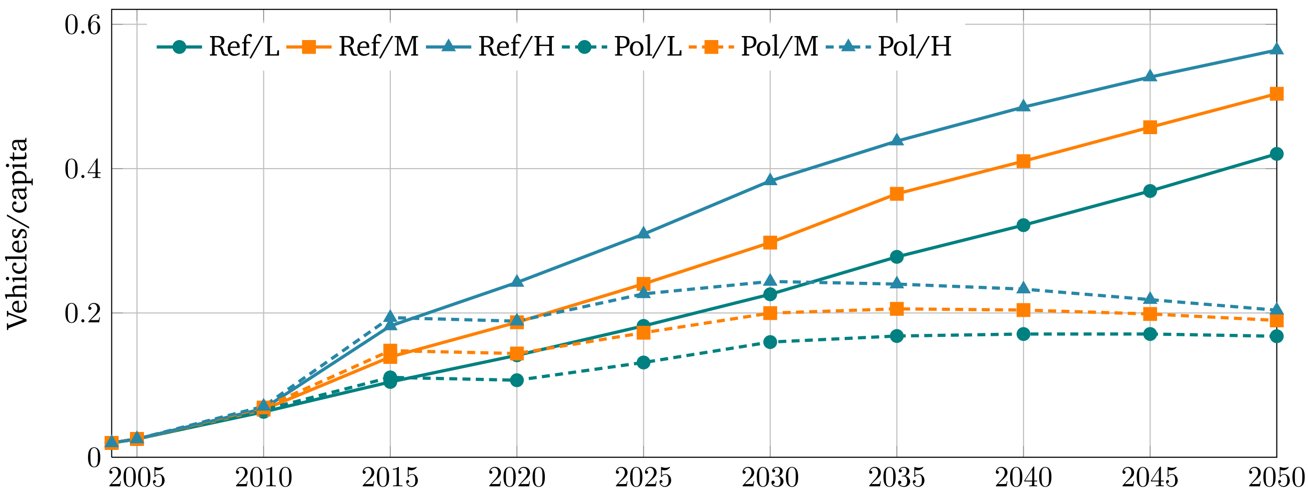

Figure 7 – Per-capita vehicle ownership, by year.

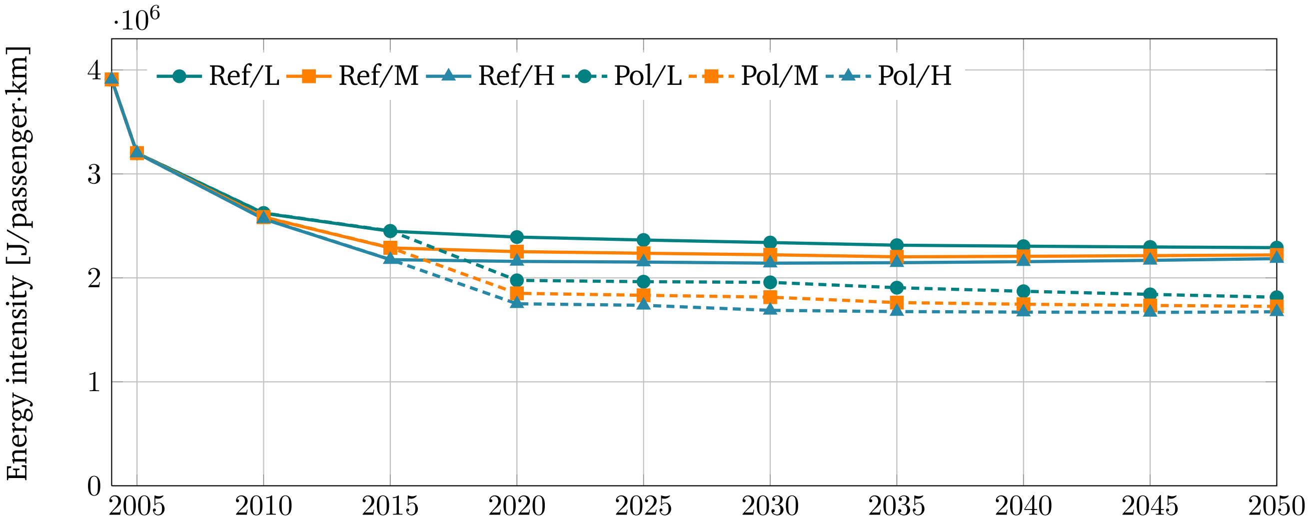

Figure 8 – Average energy intensity of household transport, by year.

Figure 5 highlights the strong impact of a binding climate policy on overall consumption. The impact in the initial period (2015-2020) is 8-9 percent of consumption relative to the reference case, rising to 17-20 percent in the final period. Compared to the base effect of policy, the incremental effect of stronger travel demand on the policy cost is small.

The magnitude and relative demand for travel by purchased and private vehicle transport are illustrated in Figure 6, with each case evolving from the current situation in the lower left. The differential effect of policy on purchased versus own-supplied modes is most visible here, with the trajectories with policy diverging in the direction of less purchased transport. Strong demand for private vehicles and the accumulated stock from early growth lead consumers to continue to operate these vehicles to obtain PKT even as they decrease their use of other modes transport. Again, due to declining population there is an overall decrease from peak travel in the later periods.

Figure 7 shows per-capita vehicle ownership in each scenario. Under policy there are significant reductions in the demand for new vehicles, with ownership approaching 200 vehicles per thousand population by mid-century. In the absence of policy, growth continues to a point where ownership approaches the present European level.

Energy and emissions intensities are given in Figure 8 and Figure 9 respectively for purchased and own-supplied transport, as well as the overall average under an example subset of scenarios. The

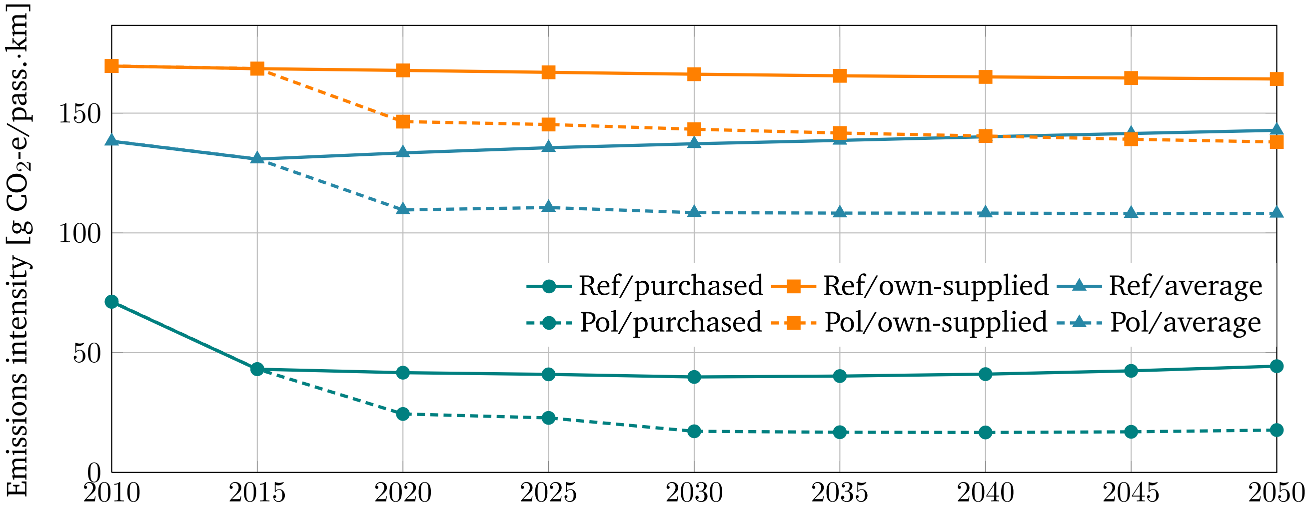

Figure 9 – Emissions-intensity of transport, by year for the high-growth scenario, with and without policy.

	Low growth		Medium growth		High growth	
	Reference	Policy	Reference	Policy	Reference	Policy
Expenditure share of transport [%]						
2030	12.5	14.2	16.0	19.0	19.4	25.2
purchased	3.6	3.1	4.6	3.9	5.4	4.6
own-supplied	8.9	11.1	11.5	15.1	13.9	20.7
2050	11.0	13.6	13.1	17.1	14.4	19.5
purchased	2.2	1.3	2.6	1.5	2.9	1.6
own-supplied	8.8	12.2	10.5	15.6	11.6	17.9
Vehicle stock [10^6]						
2030	324	231	427	293	549	356
2040	454	249	579	296	685	332
2050	568	235	680	264	762	283

Table 1 – Other projection outcomes summarized.

noticeable characteristics are, first, that improvements in energy efficiency induced by policy are more pronounced for private vehicles than for puchased modes; and second, these occur quickly in response to the implementation of the cap & trade scheme but are only extended slowly as the scheme continues.

Expenditures on own-supplied transport can also be converted into estimates of vehicle stock, by noting the share devoted to powertrain and other capital (as opposed to the fuel used to operate the vehicle); Table 1 contains these data, as well as the overall consumption share for each type of transport. The vehicle stock results for the reference cases are in line with the projections from literature (Section 2), and illustrate the large impact of even moderate auto ownership in a very large country. However, these figures also encode assumptions that the annual mileage of individual vehicles, as well as the average cost of new vehicles, will be roughly the same. The model tracks constant-quality vehicles, where spending on vehicle luxury is, at present, assumed to be captured elsewhere in the production bundle. If, as in the United States, Chinese consumers buy more expensive vehicles on average and drive them further as their wealth increases, actual stock may be lower.

5 Future work

Recent work of the MIT Joint Program has produced another version of EPPA5 with increased transport detail in the aviation sector (Winchester et al., 2011), and the combination of such detail with EPPA5-HTRN would provide information on the differential effects on Chinese demand for aviation. Similarly, recent rapid expansion of the Chinese high-speed rail network and ridership might mean that a separate treatment of this mode within the model would be of interest. Further sectoral disaggregation would allow separate modelling of changes in demand for low-speed purchased modes (as used in this study) and increases in demand for high-speed purchased modes.

As detail is added in the transport sector, care must be taken not to overconstrain the model when prescribing scenarios for studies like the current one. In particular, a robust treatment of the uncertainties in demand growth, mode preferences (including the availability of alternate modes) and factors like the scrappage rate of old vehicles is warranted. Work is underway to use a Markov chain Monte Carlo (MCMC) method (per Rubenstein and Kroese, 2007) to sample sets of parameters matching observed history, which can then be used to obtain an expected distribution of model outcomes.

Finally, to refine vehicle stock projections, domestic Chinese data on fleet characteristics of new and vintage vehicles in the model base year will be used to recalibrate the input shares of capital and fuel to private vehicles.

6 Conclusions

In this paper, we studied three pathways of increasing travel demand in China, both on their own and in the absence of an aggressive example climate policy. In particular, policy was more effective than very high demand in causing the model to take up biofuels, and a high vehicle ownership reference scenario resulted in oil becoming nearly as large a primary energy source as coal. Total ownership, even with a very large share of income devoted to transport in the high-ownership case, did not reach 600 vehicles per 1000 population in 2050. With the strong carbon quota used here, growth in fuel use and overall demand for both own-supplied and purchased PKT was arrested by about 2030.

In light of an objective to reduce energy intensity by 45% between 2005 and 2020 and other targets as discussed in Paltsev et al. 2011, Figure 8 especially cautions that even under aggressive climate policy the extent to which the household transport sector can offer reductions is limited. The high growth and resilience to policy in this segment will be a factor which offsets the impact of targeted measures in other areas. Given the great uncertainty in the literature about the range in future demand, and its consequences on emissions as shown here, alternative pathways for growth deserve attention as an important component of overall policy.

From an energy security standpoint, the outcome of the policy instrument is more encouraging, as it would constrain or reduce total demand for refined oil, in part by increasing the price of transport energy and thereby decreasing demand for all modes requiring petroleum-based fuel.

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