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Passenger transport modal split based on budgets and implication for energy consumption: Approach and application in China

Shuwei Zhang[a,*], Kejun Jiang[b], Deshun Liu[a]

[a]*School of Public Policy and Management (SPPM) and Institute of Energy, Environment, and Economy, Tsinghua University, Beijing 100084, China*
[b]*Energy Research Institute, National Development and Reform Commission, Beijing 100084, China*

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Abstract

Transport will be the strongest growing energy demand sector in the future, especially in developing countries like China, and it needs more attention. The evolution of transport structure is very important in the dynamic of transport development, and therefore worth emphasis. In this study, a modal split model maximizing spatial welfare and constrained by travel money budget and time budget is developed. This approach differs from the general econometric-based approach used in most existing macro transport studies and deals with the cost and speed of transport modes as important variables explicitly. The model is then applied to China's transport sector together with sensitivity test despite many data problems. The decomposition of energy consumption generated from bottom-up model based on this modal split identified the importance of modal split and turnover expansion in the next 30 years, which should be a stronger area of focus in transportation studies.

Keyword: Transportation; Modal split; Energy consumption

1. Introduction

The transportation sector has experienced steady growth in the past 30 years and the resulting energy consumption from transport has sustained a 3.7% annual growth rate from 1971 to 2003 (IEA, 2005), increasing its share of final energy use. More seriously, the transport sector relies almost completely on "scarce" petroleum products. For the future it is expected that transport will continue to increase its share in the global energy demand. This is due to increasing mobility demand from globalization of the whole economy as well as the rapid increase in economic activity and the increasing consumption of private cars in developing countries, especially some huge catch-up countries like China and India. The significance of this growth can be seen from the relationship between GDP/capita and transport share in final energy (Schafer, 2005), which is almost a linear link in the past years. Specifically in China, the energy consumption in transport sector has grown more than 10 times (10.4), almost in-phase with GDP growth (11 fold increase) from 1978 to 2005 (IEA, 2005; NBS, 2006). So it can reasonably imagine that when the GDP/capita in developing countries approach the current level of industrial countries, energy demand for transportation will be a significant portion of total energy use. It is therefore necessary to give attention to the transportation sector.

As a result, proper modelling of transport has become more important to explore the necessary infrastructure construction as well as potential energy consumption, oil security, and pollution issues resulting from the transport activities. Three factors which are key determinants of final energy use in the transportation sector include activity, measured in passenger kilometers (pkm) for passenger transport and ton kilometers (tkm) for freight transport; structure, measured in modal shares of total pkm or tkm; and modal energy intensity, measured in energy use per pkm or tkm. Using the completed decomposition model introduced by Sun (1998), Zhang (2006) measured the relative contribution of different factors in China's transport energy consumption and found increased activities

*Corresponding author. Tel.: +86 10 62772746; fax: +86 10 62771150.
E-mail address: Shuwei.zh@gmail.com (S.w. Zhang).

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and modal shift to road (including bus and car) transport were two key factors driving energy demand in the past 20 years (1980–2002). Prior to 2000, the benefit effect from declines in energy intensity did not offset the growth of the former two factors. After 2000, the energy intensity increased, in part because of a decline in the load factor of road and railway transport as well as an increase in fuel intensity (measured in energy use per vehicle km (vkm)) because of speed acceleration, especially railway. These results reflect the relative importance of each component of change in energy use. In the future, possibly similar with the passed years, rapid increases in activity and continued modal shifts are expected to push up energy consumption, unless there is radical fuel intensity decline via policy changes, technological innovation and/or behavioral adaptation (Scholl et al., 1996).

However, the modelling of transport structure evolution in medium to long-term projections is far from satisfactory. The structure is overlooked in some studies about the entire transport sector. In these cases, the transport modes are treated independently and econometrics or elasticity-based methods for each mode/vehicle type fail to consider the competition and saturation of modes/vehicle (e.g. Walsh, 2002; Kobos et al., 2003; He et al., 2005). This kind of extrapolation method is more problematic for countries with short historic time series and rapid development, which often result in very high growth rate of transport systems and it is difficult to judge when the inflection point in the growth trajectory will appear.

Breugem et al. (2002) give a review of the passenger model in the energy economics fields. Many determinants for modal shift are well identified in the referred papers, such as the IEA transport model, WEC model (Schafer and Victor, 2000). Schafer and Victor's work is regarded as a big progress on this issue, which takes into account the competition between modes and "sum to 1"[1] characteristics explicitly. Many papers in transportation studies adopted this model, e.g. Miketa and Schrattenholzer (2003), Turton and Barreto (2004) and Christian et al. (2000).

But because the Schafer/Victor model is basically dominated by econometrics and most of the parameters are derived from historic regression, it is difficult to consider the policy intervention and construct different scenarios but the baseline. As a global model, it must sacrifice some specific attributes of countries. Taking China as an example, there is a huge gap between rural and urban area, in both economic and social attributes. In rural areas, the non-motorized forms of transport (such as bicycle and walking) are still dominating; however these modes are fast substituted by motorized ones (such as private vehicles or buses) in urban areas. This high heterogeneity calls for necessary disaggregation between urban and rural people in the analysis to avoid potentially misleading trends. Also, intracity and intercity transport should be differentiated because they may have different options, driving forces and priority sequences. These will be interpreted in Section 2.1.

Presently, modal split in (urban) transport planning is gradually being applied to macro level (national, international, regional) transport study. The discrete choice model with the characteristics of "sum to 1" and utility-based formulation are popular and related variant model are used, such as multinomial logit (MNL), nested logit (NL), mixed logit (e.g. Horne et al., 2005; Schafer, 2006).

My work in this paper can be seen as a parallel approach to simulate the modal split. Here a modal split model inspired from Zahavi's budget concept is formulated and applied to the case of China with the differentiation of people group (urban and rural) and transport type (urban and intercity transport). Before illustrating the model itself, travel money budget (TMB) and travel time budget (TTB) are discussed specifically for China in order to make clear some key issues in Section 2.2.

The remainder of the paper is arranged as below. In Section 3 the modal formulation is illustrated. Then the application into China's transport development is presented in Section 4. The sensitivity analysis is given in Section 5 to imply the model's strength and weakness. Finally the summary and discussion on statistical system are given in Section 6.

2. Options and constraints in passenger transport activities

2.1. Options

Comparing with most industries, the distinct feather of transport is various technologies with quite different performances exist in this sector. In term of intercity transport, car, bus, railway, and aircraft are four basic modes people can choose, and for urban transport, because the travel scope is smaller, many non-motorized and simple modes are optional, such as walking, bike, motorcycle, 2 or 3 wheel vehicles. Obviously, the aircraft cannot be used for intracity transport even in the far future, and people also cannot use walking as an option in intercity travel.

Except the options, the driving force for urban and intercity transport is also different. Disposable income, improving transport infrastructure, and population expansion are all driving forces for the inter- and intra-city transport. In term of urban transport, most of them are obligatory, such as commuter, daily activities and inelastic to cost variance like food. Moreover, only the modes of transport change (from non-motorized ways to motorized ones) can bring the obvious turnover increasing given the time used for transport is limited. The modal change only occurs when people's income has a large growth because of huge cost gap among transport modes, which also show the low elasticity attribute. In contrast, the intercity choice is sensitive to the income change. The elasticity of intercity transport to GDP/capita in China is 0.7 or so in the past 20 years.

[1]That means, the sum of the shares of all the modes should be equal to one because they are competitive and contained in one system.

This can be regarded as heterogeneity and make us to consider the modelling of transport more reasonably (Grubler, 2006), i.e. treating them separately because of different options and driving force pattern. In China where cities are transport centers and junctions with clear boundary the urban and intercity transport is distinct. At the same time, people will allocate the limited resource, including time, money to all of the transport ways, so an integrated frame linking them together, other than independent estimation, is also necessary.

2.2. Constraints

People's demand for transport rises in the need of work, shopping, visiting and so on from one place to another and they will pay for them and cost some time. Money and time are two of the most obvious elements on people's transport behavior and choice. For one single trip people pursuing, maybe it is difficult to find some principle. But aggregated into certain level, some "statistical" law is found in many literatures, e.g. the introduction of budget concept and discussion on its stability.

2.2.1. Zahavi's model and TTB issue

In 1980s, Zahavi (1979, 1980) observed that on one day people with travel record spend 1–1.5 h or so in urban area, whatever in sample cites of US, Germany, Brazil, or Chile. The time used varied with urban characteristics, topography, population density, income, urban layout (asteroidal or linear) and so on but the distribution range is very narrow from the time series and cross-section transport survey data and can be considered as constant. After that, Schafer (2003) considered this issue again using the new survey data[2] at the end of last century, and drew the similar conclusion with Zahavi. This principle can be named travel time budget (TTB).

The principle was also identified in term of the money used for transport. That is, household with a car will spend 10–15% of their total disposable income in the transport, and for the household without a car, that figure is 3–5% in Zahavi's study. This proportion is constant also even in the oil crisis period, when people reduce other transport costs (e.g. buying cheaper cars) to offset the fuel price rising. This principle is named as travel money budget (TMB).

With TTB and TMB as constraints, Zahavi (1979, 1981) developed an urban transport model and apply into the urban transport planning and interaction with land.

The stability of TTB and TMB is fundamental in Zahavi's model and there is much controversy about this. While there are many other literatures (e.g. Szalai et al., 1972) identified the existence and stability of budgets through transport surveys, after all this is only statistical regularity and it is unclear why this occurred from the perspective of traveler's behavior. Moreover, different data source may give inverse conclusion. In the review by Mokhtarian and Chen (2004),[3] they generally think that "travel time expenditures are not constant except, perhaps, at the most aggregate level ... the definitive existence of constant travel time and money budgets in time and space is not supported ... the underlying mechanisms explaining that regularities are not well understood". Seems there is no consensus on this issue.

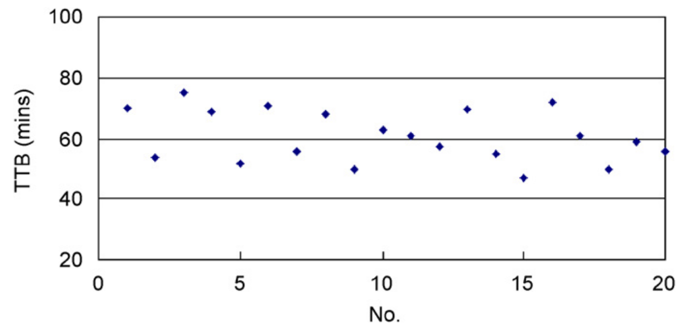

Fig. 1. TTB in China's 20 cities.

2.2.2. TTB in China

In order to check TTB in China, transport surveys in 20 cities are collected and the TTB used by per person[4] are roughly calculated (Fig. 1). In term of the population size, there are 4 super maga cities (>2 million), 9 maga cities (>1 million), 4 big cities (>0.5 million), and 3 medium cities (>0.2 million). There are no small cities data (<0.2 million) available in our sample. The maximum, minimum and average value is 72, 50, and 61 min, respectively. The coefficient of variation is 0.14, lower than that of the study in cites of developed countries in Zahavi (1979).

No surprise, there are some factors to bring the variance of TTB. Regressing variance of TTB and related socio-economic factors, the population size in urban area is identified to be critical factor to affect the fluctuation of TTB in China, and the other factors, such as population density, income and metro existing or not have minor influence. The linear equation of variation of TTB is given below:

$$\begin{aligned}\text{Delta (TTB)} = {} & 0.00048 * \text{POP\_DENSITY} + 0.01 \\ & * \text{POP} - 5.86e^{-05} * \text{INCOME} - 1.4 \\ & (0.38) \quad (1.77) \quad (-0.38) \quad (-0.28),\end{aligned}$$

[2]The sample includes the cities not only in developed countries, but developing ones, such as some countries in Africa.

[3]In Mokhtarian and Chen (2004), the difference between "expenditure" and "budget" is given. The word "expenditure" does not imply stability. On the other hand, the word "budget" implies stability, referring to an "allocation of time, money or generalized resources to travel which would not be influenced by policy, trends or costs." But in this paper, we still use "budget" as constraints of the model in an aggregated level, leaving the issue of stability aside at this period. Also in Zahavi's study, "budget" does not means stability, only proportional share to income.

[4]Among these 20 cities, only several disclosed the trip number per day for per traveler. So here the discussion is specific in TTB per person, which is different to Zahavi's study, but same with some other studies referred in the review of Mokhtarian and Chen (2004) on the section of "analysis unit", p. 15.

where, delta (TTB) is the variance of TTB of specific cities to average TTB; POP_DENSITY, population density; POP, population size; INCOME, average disposable income for urban people.

The t-value of this regression is 1.746 under the 5% significant level, and the statistical relationship roughly remains but not significant. It can be said that the TTB is plausibly stable in China's urban people travel across cities, and varied small with population scale. For the TTB variance across time, it seems that an obvious increase exists from limited several city samples, which I do not propose to discuss further given convincing survey data unavailable.

2.2.3. TMB in China

The existing transport survey cannot provide the expenditure data, and the analysis can be from the survey on people's income and expenditure structure. In China, the yearbooks of *China price index and family income and expenditure survey of urban residents* provide the transport expenditure series for urban people.

Consistent with the statistical scope, whether occupying a car or not is not divided explicitly and only the available aggregated trend of TMB is analyzed. When people have less income near ZERO, the transport will be 100% non-motorized ways, and the expenditure of transport near ZERO also. With the growth of income, the motorized transport will be introduced and the expenditure increases gradually. When the private car penetrates into people's daily life, the TMB share in disposable income is bigger. But the TMB will be converged on one certain level (e.g. about 15% out of income) where the expenditure share on transport saturates because of high car occupancy rate (Schafer's study shows it is about 200 vehicles/1000 cap). So according to this logic, the relation between TMB (%) and disposable income can be simulated by the curve below:

$$\mathrm{TMB} = a - \frac{b}{(\mathrm{income}+c)^d},$$
$$a = 15\%,$$
$$d > 0,$$
$$c > 0,$$
$$b = 0.15 * c^d,$$
$$\mathrm{TMB}' = b * d(\mathrm{income}+c)^{-d-1} > 0,$$

where, a, b, c, d are regression parameters.

This curve is an asymptote near 15% with disposable income increase. Using the panel data into one basket to estimate the parameters, the regression result in China from 1993–2005 is

$$\mathrm{TMB} = 0.15 - 0.15 * (1771)^{0.13}/(\mathrm{INCOME} + 1771)^{0.13}.$$

The model will be formulated below with TTB and TMB as basic variables and constraints.

3. Model formulation

Zahavi's work (Zahavi and Talvitie, 1980; Zahavi, 1981) mainly considers the urban transport, and the discussion for the intercity transport is preliminary. Inspired from that, this model will integrate urban and intercity passenger transport together and they share the total budgets under some mechanism derived from empirical conclusion and logic.

The storyline of the model is: assuming that a representative person allocates to travel a (average) money budget and a (average) time budget per day and the transport activities will have M available modes with different travel speed and cost combination (cost, speed). The question is by what combinations of modes the person can maximize its spatial economic opportunities, as represented by the total travel distance (Zahavi, 1979). So in this model, the distance represents one kind of utility, not cost like that in traditional transport planning people must overcome. This is called "the welfare of scope". More scope means more opportunities.

The basic formulation is listed below. Firstly, the representative person maximizes the urban travel distance using the combination of transport modes with the constraint of time and money expenditure for urban transport.

$$\mathrm{Max} \sum_i \log(X_{isd} + \Delta X_{isd})$$

s.t.

$$\sum_i \frac{(X_{isd} + \Delta X_{isd})}{S_i} \leqslant TT\,B \Rightarrow \sum_i \frac{X_{isd}}{S_i} + \sum_i \frac{\Delta X_{isd}}{S_i} \leqslant TT\,B \Rightarrow \sum_i \frac{\Delta X_{isd}}{S_i} \leqslant 0$$

$$\sum_i M_i * (X_{isd} + \Delta X_{isd}) \leqslant \mathrm{TMC} \Rightarrow \sum_i (M_i * X_{isd} + M_i * \Delta X_{isd}) \leqslant \mathrm{TMC} \Rightarrow \sum_i M_i * \Delta X_{isd} \leqslant \Delta\mathrm{TMC},$$

where, i, the transport mode considered in the model, $i = 1, 2 \ldots, M$; X_{isd}, the travel volume by mode i in the urban transport (sd means short distance, refer to the urban transport, Unit: km). For a given period t, it will be transferred from the $t-1$ period and can be looked as exogenous variable;[5] ΔX_{isd}, the growth of travel volume by mode i in the urban transport comparing with the previous period (km); TTB, time expenditure for urban transport (h); TMC, money expenditure for urban transport (Yuan); ΔTMC, the growth of money expenditure for urban transport comparing with the previous period (Yuan);

[5]It should be noted that the time and money resource left (if exits) in the previous period can't be transferred to the current period. Under this condition, the derivative formulation is valid.

S_i, the travel door-to-door speed of mode i (km/h); M_i, the travel unit cost of mode i (Yuan/pkm).

Then, the "average" people will maximize the intercity transport, using the remainder of time and money resource.

$$\text{Max} \sum_i \log(X_{ild} + \Delta X_{ild})$$

s.t.

$$\sum_i M_i * \Delta X_{ild} \leqslant \Delta\text{TML}$$

$$\sum_i \frac{\Delta X_{ild}}{S_i} \leqslant \Delta\text{TTL}$$

where, X_{ild}, the travel volume by mode i in the intercity transport (ld means long distance, refer to the intercity transport, Unit: km). For a given period t, it will be transferred from the $t-1$ period and can be looked as exogenous variable; ΔX_{ild}, the growth of travel volume by mode i in the intercity transport comparing with the previous period (km); TML = TMB−TMC, the money used for intercity transport is the residue between the total money budget used for transport (TMB) and that used for urban transport (TMC); ΔTML, the growth of TML comparing with the previous period (Unit: Yuan); ΔTTL, the growth of travel time expenditure for the intercity transport comparing with the previous period (Unit: h). From the historic data and logic judgment, the time used for intercity transport t is only several minutes per day, and the figure in the projection period can be set by historic extrapolation or scenario assumption.

The model can generate the activity volume of each transport mode i, and then the modal share can be obtained by the quotient of individual transport volume and total transport volume.

It should be noticeable that the model gives the optimization on the margin, i.e. using the growth resource to increase the transport. So the calibration is not necessary for the model itself. However, because of the issue of data availability, the output of the model must be "compared" with the base year data to ensure the model's validity. At the same time, the model can optimize the transport behavior to the past year and adjust the boundary conditions and parameter to fit the historic trend. If there are some obviously unrealistic results like the flip-flop problem, some extra constraints, including infrastructure supply capacity limitation must be added. Now there are some constraints on metro and motorcycles' growth.

Matlab 6.5 and the optimization toolbox will be applied to solve this modal split model. The transport modes of urban transport considered in the model include car, bus, metro, walking, bicycle and others (now the motorcycle's characteristics are set for the "others" mode); the intercity transport includes car, bus, rail and aircraft. The waterway transport is negligible. The cost and speed of each mode is represented by one standard proxy's characteristics. The model will be iterated in 5 year steps from 2002 to 2032 in China case.

4. China case

4.1. Disaggregating into urban and rural group

As we know, the gap between rural and urban, east and west region inside China is very obvious and for the transport activities, the heterogeneity is obvious especially in term of urban and rural people. The urban people, with a higher disposable income and better transport infrastructure, have a larger travel scope with advanced transport vehicles, such as private cars. Contrastively, the rural people have a lower income and spend little money (TMB) on the transport and the travel of long distance is rare and non-motorized ways dominate the short distance. Also, the cost and speed in rural and urban area is also different because of varied market volume and infrastructure quality. Reasonably, China is disaggregated into urban and rural people group in this case and the model solves them separately and finally aggregate into whole country.

4.2. Data

The data classification is illustrated in Table 1 and some guesstimates and approximation are given.

4.2.1. Cost

The cost for car is also an average concept, i.e. cost proxy from a classical car and travel behavior. Car cost per travel unit was subdivided into fix cost and operating cost. The former comprise the depreciation, maintain, tax and repair cost, detailed in Table 2. The latter comprise expenditures on fuel, depending on fuel economy and fuel price.

The costs of other modes are only ticket cost consumer face, mainly from CCTA (1999) and authors' judgment (Table 3). They can also be looked as proxies.

Table 1
Data classification in China case

	Urban people	Rural people
Total	TTB-1 h TMB-asymptote	TTB-1 h TMB-asymptote
Intracity transport	TTC-1 h TMC-share of TMB, obtained through urban survey and historic estimation	TTC-1 h TMC-assuming it as ZERO now and endogenous in scenario
Intercity transport	TTL-only several minutes, set by historic trend, and scenario assumption TML-residue between TMB and TMC	TTL-only several minutes, and assuming the future trend. TML-equal to TMB

Table 2
Cost component of car

	Item	Value
Fixed cost related	Fix cost (car price, Yuan)*	80 000
	Maintain, and repair (Yuan)	2500
	Tax (Yuan)	1000
Operating cost related	Annual traveled distance (ADT briefly, km)	16 000
	Average fuel economy (Liter/100 km)	8
	Average load factor	1.5
	Fuel cost (Yuan/l)	3
Total cost (Yuan/pkm)		0.60

Note: The calculation of car is based on a purchase price of 80 000 Yuan, a life span of 10 years, an average annual traveled distance of 16 000 km and a load factor of 1.5 per standard car. The resulting car cost is hardly observable in real work because of fix cost involved and will be the "swing" variable to produce base year mobility levels considering the possible inconsistency between the meaning of cost and the expenditure per person reported in the statistical system above.

Table 3
Cost and door-to-door speed of modes

Modes	Speed (km/h)	Cost (Yuan/pkm)
Urban transport		
Car	25	0.6
Bus	10	0.1
Metro	15	0.3
Walking	5	0.001
Bicycle	8	0.01
Others (Motorcycle)	10	0.2
Intercity transport		
Car	40	0.6
Bus	30	0.12
Railway	20	0.05
Aircraft	600	0.8

4.2.2. Speed

The network speeds can be obtained from the transport survey in some sample cities. The network speeds were divided by a factor of 1.5 in order to derive the door-to-door speeds, which only can be regard as a rough estimate. The value of speed could be a good proxy to represent the attractiveness of different modes.

4.2.3. Constraints of the model

The time and money people allocated between urban and intercity transport is necessary to determine the boundary of the optimization model. In term of the urban transport, a constant budget of 1 h and no increase in future is assumed whatever for urban and rural people. For urban people, the money share of urban transport is about 40% in base year and this share will be assumed to keep in future.[6] In term of time used for intercity transport, according to the historic trend, an annual increase of 1.5 h for urban people and 2 h for rural people are set in this reference case. For rural people, the short distance transport is roughly assumed to be dominated by non-motorized transport and no expense, and all of the expenditure will be used for intercity transport. A similar pattern with urban people is set in term of money expenditure trajectory. Merely they will be at the low part of the curve because of low income.

In Section 5 the potential impact of constraint variation, i.e. sensitivity test will be analyzed further, including the money distribution between urban and intercity transport and the stability of urban TTB.

4.2.4. Socioeconomic scenario

According the national 11th Five-Year Plan of China and long-term target for the year 2020, the socioeconomics assumptions are listed in Table 4. Among them, the income series will be the input variables of modal split model developed in Section 3.

4.3. Result

Together, the model and data will generate the passenger modal split during the projection period, 2002–2032. Fig. 2 reports the results aggregated into the national level.

The share of car and aircraft in intercity transport by 2032 will grows to 29% and 24% because of their speediness, offsetting the decline of railway and bus. Different from the intercity transport, the modal substitution in intracity mainly occurs in substitution of motorization way to non-motorization ones.

Combined with AIM/enduse, which is a technology model with cost minimizing choice mechanism to generate the energy consumption and emission. The details on AIM/enduse and the construction of vehicle technology database is beyond the scope of this paper, see AIM Project Team (1996) and Zhang (2007) for further information.

The relative contribution of different factors to the energy consumption can be measured using the complete decomposition model again. The result for intercity transport in 2002–2032 is shown in Fig. 3. Even in the next 30 years, the contribution of activity expansion and modal shift explain most of the growth of energy consumption, and the decline of energy intensity will be a negative factor to affect the energy consumption but its effect is too minor to offset the impact of the former two. This conclusion is similar with Zhang et al. (2006) on the China's transport energy consumption in 1981–2001. So

[6]With income growth, when most of the people use private car or the substitution of modes stop in the urban transport, the expenditure in urban transport will saturate and the share will decline and be offset by the gradual increase of expenditure in intercity transport. But now it is difficult to judge when this will occur, so a constant share is assumed simply.

Table 4
Socioeconomics assumptions in scenarios

	GDP (10^8 Yuan, 2002 value)	Population (10^4)	Urban population (10^4)	Urban income (Yuan, 2002 value)	Rural population (10^4)	Rural income (Yuan, 2002 value)
2002	120333.0	132 185	57 556	11 277	74 629	3330
2007	192331.4	136 621	61 459	12 644	73 297	3732
2012	257415.5	140 969	63 778	14 103	72 843	4592
2017	368606.1	144 154	71 421	17 751	69 548	6742
2022	492014.6	145 789	73 674	19 940	69 379	8032
2027	641496.0	146 213	77 701	21 567	66 453	8688
2032	772809.2	132 185	83 082	26 240	62 707	10 570

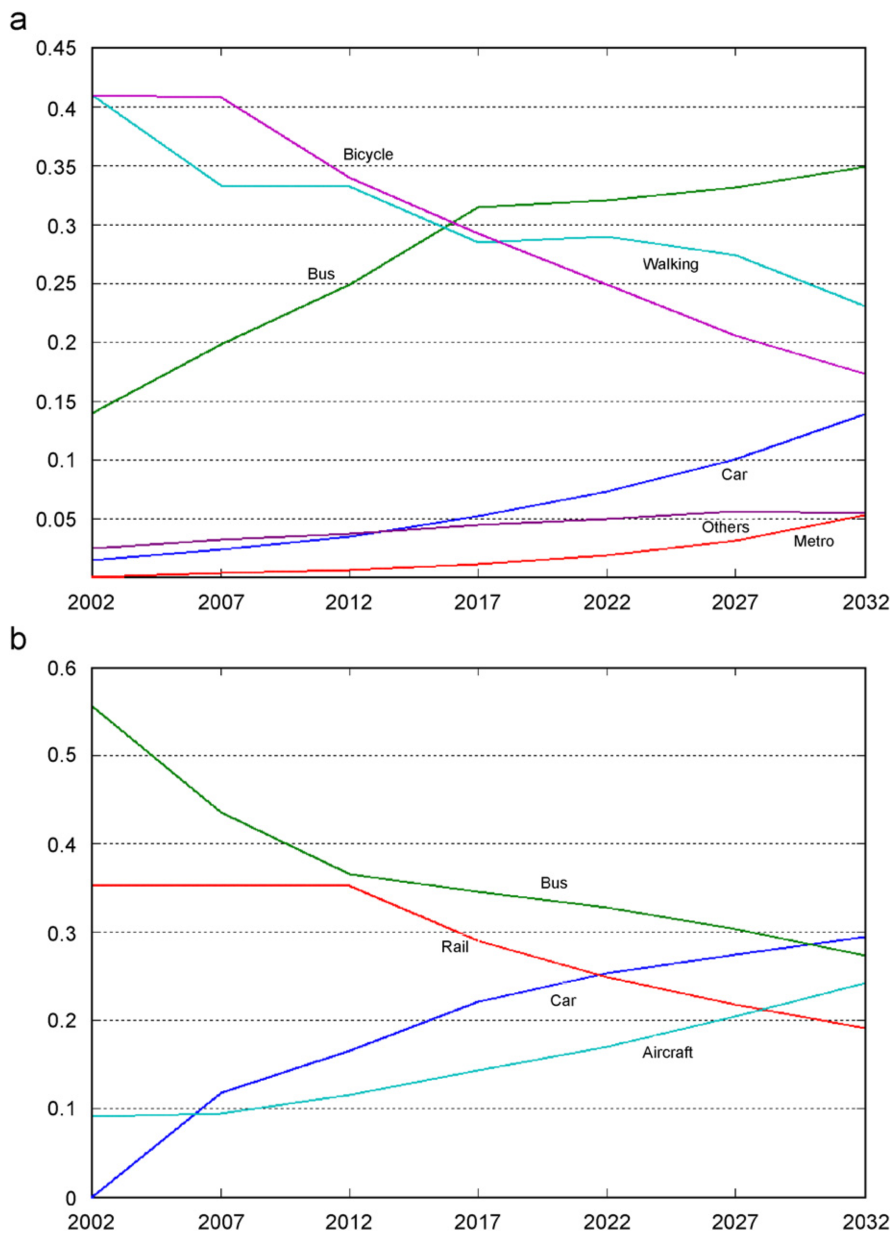

Fig. 2. Modal split in urban and intercity transport. *Note*: The unit for urban transport (a) is share in the total trip number, and that for the intercity (b) is share in the total turnover (pkm).

from the strategy perspective, the transport study should emphasize on the determinants and projection methodology of transport activity and modal split, other than pure technology analysis in most extant studies, especially in a short- and medium-term when radical technology change is impossible.

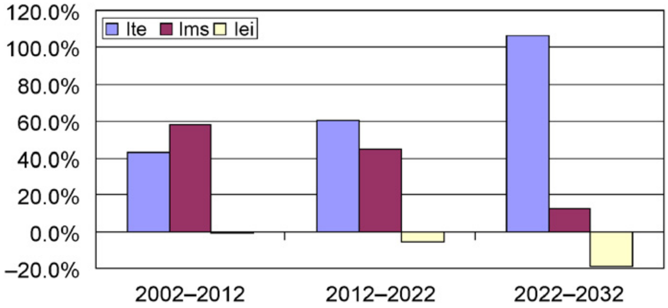

Fig. 3. Factor relative contribution to energy consumption growth in intercity transport. Note: the *Ite*, *Ims*, and *Iei* represent the effect of turnover expansion, modal shift and energy intensity decline respectively.

5. Sensitivity of result

Generally speaking, the performance of modes is quite different, so minor change in cost or speed does not significantly affect the result. But for the constraints, small change in the budgets may change the optimal travel combination. So the potential variance of the constraints is emphasized in this section.

5.1. Stability of TTB for urban transport

In the previous section, the increase of TTB in the historic is observed in limited samples, and here the possible effect of this is tested.

Fig. 4 illustrates the sensitivity of the modal share in 2032 to a sequential increase in TTB, from 5%, 10%, 15% until 20% for urban transport. The result shows that the change trend for the car, metro is monotone to decline, but the bus is not. This can be explained from the two effects of TTB expansion. First, the time resource is richer and all of the transport modes tend to increase (positive), and at the same time, the substitution effect of non-motorized ways by motorized ways is also affected negatively. When the time increase by 5%, the share of non-motorized ways increase mainly because of the dominated resource expansion effect and with the resource continue to increase, the substitution effect become more obvious and the bus will increase the share with loosing time constraints.

Generally, the result is sensitive to the possible TTB variance, especially the fastest mode, car transport. So the discussion on the stability and trend of TTB is meaningful in many current literatures mentioned in the first section and the TTB trend in China need to explore further as a priority.

5.2. Money distribution between urban and intercity transport

According to the general logic on the dynamics of money expenditure on urban and intercity transport, a linear growth of money from 60% to 70% spent in intercity transport out of the total expenditure in transport is set to assess the possible variance of the result (Fig. 5).

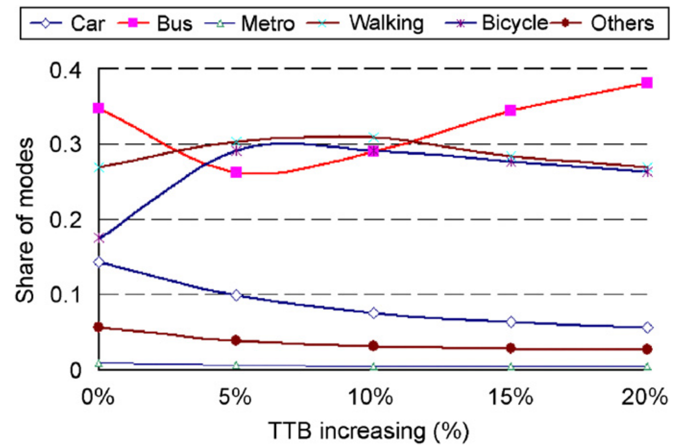

Fig. 4. Modal share variance with TTB expansion.

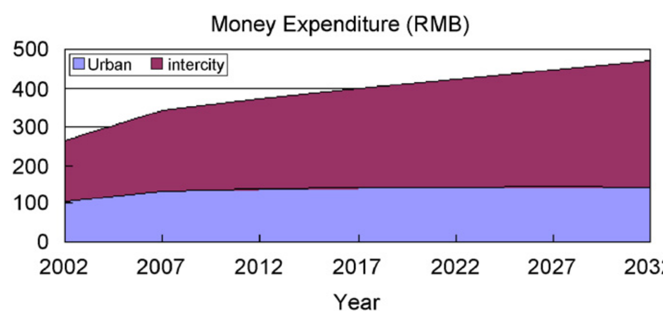

Fig. 5. Money expenditure spent on urban and intercity transport in sensitivity test.

The result shows that the change of modal share in intercity transport is minor. Even in 2032, comparing with the results of the reference case above, aircraft increase its share by less than 4% from the decline of car, bus and rail lose, all of which decline by 1% or so. Sharply different from this minor change, the share change is considerable in urban transport because of almost constant money resource (which can be seen from Fig. 5). The substitution of walking and bicycle by car and bus is becoming slower, and even in 2032, the share of non-motorized way is about 60%, which is 40% in the reference case.

Results could also be affected by the cost and speed parameter of each mode, the test shows that the moderate change (less than 10%) in them does not change the result much.

The sensitivity test has identified that urban transport is very sensitive to the variation of time and money constraints in term of modal share. On one hand, it is normal because cost and time available in reality are two key variables to determine the transport evolution. On the other hand, most of data unavailable in urban transport possibly affect the accuracy of the result.[7] The base year

[7]This is part of the reasons why many China's transport studies totally overlooked the urban transport part, e.g. Skeer and Wang (2007), Huenemann (2001).

data, including the trip share by each mode, trip number and so on, is arbitrarily estimated on several cities listed here. So the conclusion about the urban transport must be carefully treated. The intercity transport evolution from this study is much like that trajectory using the logistical substation model (Marchetti and Nakicenovic, 1979). The bus and rail is declining and the car dominates the transport in these 30 years but already near saturation, and the aircraft grow very fast and offset all of the decline of other modes. It seems robust.

6. Conclusion

In this paper, the modal split model maximizing the spatial welfare constrained by travel money budget and time budget founded by Zahavi are developed, and applied into the China's transport study. The model's strength is mainly:

(a) The model considers the competition, saturation level and "sum to 1" attributes of transport modes, which is more consistent with the empirical finding of transport studies.
(b) Fit the policy analysis. The traditional modal split in the macrotransport study is basically qualitative judgments, which is lack of accurate and transparent estimation for the effect of policy, as well as econometrics estimation. In contrast, This approach deals with the cost and speed of transport modes as important variables explicitly, which can help assess the impact of alternative policy case more easily.
(c) Differentiation between intracity and intercity transport is more proper for transport development, which is more reliable comparing with aggregated econometrics methods.
(d) The time and money budgets are transferable cross time and location if the principle of TTB and TMB is accepted and verified.

This endeavor in modelling of structure change in transport can provide some insight into several aspects for China's transport development and study. First, the model results in a medium term and factor decomposition of final energy identifies the importance of turnover expansion and modal evolution in transport energy consumption, which should be a stronger area of focus in future transportation studies.

Secondly, from the perspective of modal data set, the transport statistical system should be necessarily improved. Now the transport in China is administrated and governed by different bureaus and the separation of management is serious. The intercity passenger and freight data is collected by the ministry of transport. The ministry of construction is responsible for the urban transport, which is not contained in the total transport statistical system. In the past time, the motorization rate in cities is very low and the scale and number of cities is small, this approach is out of big problem. But now the urban transport has achieved much development and the private vehicle is more and more active in urban transport. The fuel consumption of urban vehicle is already one half of the total passenger transport energy consumption or so (Wu, 2005). The inclusion of urban transport into the whole transport system is necessary.

The model derives the solution as non-linear programming. Although the logarithm function is stable in most case, but there will be some unrealistic "flip-flop" optimization behavior because only demand side (time and money) variables are considered. This needs some extra supply constraints to reflect the investment capacity limitation on the supply side. This harms the function performance of model, and need more analysis on their role and impact on the feasible solution. A module containing investment behavior is a reasonable extension of this approach to solve this problem for good.

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