

Gasoline Tax? A System Dynamics Study of Private Passenger Vehicles in China

by

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Abstract

Scarcity of oil and increasing demand make the crude price continue to climb, and such pressure urges our effort to reduce the reliance on oil products. As a major consumer of oil synthetic fuels, the transportation sector needs to take a big step in energy conservation. To inform policy makers of costs and benefits in the future of decisions made now, this paper develops a system dynamic model to explore the role of gasoline taxation in the process of fuel economy technology development and adoption.

The model focuses mostly on the interplay of gasoline price change, car consumer choices and automakers technology investment decisions. It is built and simulated in the context of China and its growing private passenger car market. Gasoline tax, tax refund, technology development subsidy are tested and compared.

When the gasoline price increases, the sooner we impose the gasoline tax, the better. Even though we face a cost increase right after the tax imposition, we can enjoy a much lower cost later and cover the cost increase before. Taking the tax as subsidy for technology development of fuel economy, a much better benefit can be enjoyed.

Key words: System Dynamics, Private Car, Fuel Economy, Gasoline Tax

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Chapter 1 Introduction

Two centuries ago, the first industrial revolution made people a hundred times more productive, harnessed fossil energy for transport and production and nurtured the world economy (Lovins et al. 2004). While still enjoying all the benefits from oil employment, we have to admit the problem - Oil is the lifeblood for modern industrial economies, but not forever.

The scarcity of crude oil and increasing demand has driven the price to \$75.35 per barrel, a record high on April 21, 2006. Crude oil imports into the world's second biggest consumer, China, rose 3.5 percent in 2005 and 34.8 percent in 2004, according to customs data. Crude imports may reach 160 million tons (about 3.2 million barrels a day) from last year's 145 million tons, China Petrochemical Corp., the nation's largest oil refiner, said in its online newsletter in March. China's oil imports may rise 10 percent this year, a slower pace than last year's 14 percent, as government policies to boost energy conservation cuts fuel consumption. (Bloomberg 2007)

As oil supplies are becoming more concentrated and less secure, the more we depend on oil, the more vulnerable our economy will be. To reduce our reliance on petroleum products, we can turn to energy conservation, which is the practice of decreasing the quantity of energy used while achieving a similar outcome of end use.

Over the next twenty years, transportation is expected to be the major driving force behind a growing world demand for energy. It is the largest end-use of energy in developed countries and the fastest growing one in most developing countries. The transport sector represents nearly 30 percent of total emissions of carbon dioxide, the primary contaminant responsible for global climate change. Further, with rapid growth in motor vehicle use in the developing world, the sector is also the fastest growing source of greenhouse gas emissions (Economic and Social Council, U. N. 2001). Thus, transportation must play an active part in energy conservation.

The transportation sector includes all vehicles used for personal or freight

transportation. Of the oil used in this sector around the world, approximately 75% is consumed by road vehicles. Air traffic consumes about 12%, sea consumes about 7% and train plus river transport consume most of the remaining 6% (Cui 2006).

In 2004, road traffic contributes 1/3 to the total oil consumption in China. As automobiles become more and more popular in China, fuel consumption is expected on rise continually. However, the 100-km fuel consumption in China is 10%-15% more than that in developed countries (Chinese Academy of Engineering 2003).

The continual rising gasoline consumption spurred the creation, in 2004, of the Passenger Vehicle Fuel Consumption Standard program, which required auto manufacturers to meet progressively fleet fuel economy targets according to vehicle weight. It targeted to reduce its average 100-km fuel consumption by 5%-10% in 2006 compared to that in 2000, and by 10% in 2009 compared to that in 2006. The next few years saw advocates for economy vehicles and some improvements in fuel economy, mostly the result of relaxation of small car limitation in large cities. These gains eroded somewhat due to people's perception of 'poor-looking' and 'poor matches of social identity' for economy cars, which makes automakers prefer to improve looks rather than fuel efficiency.

Since overall average fuel economy on road did not improve as expected, the China government comes to realize the market itself is not efficient enough to push technology development and adoption in auto industry. The standard itself may lead auto manufacturers to take chance meeting the minimum level of fuel economy without any further improvement. In addition to extension of fuel consumption standard to freight fleet, the government has begun to think about gasoline tax to encourage purchase and production of better fuel efficiency vehicles.

This potential policy has received much attention and much research has been done to declare its positive and/or negative effects. Some analysis may only consider situations on the end-state of policy implementation, which are too simplistic to appreciate the complexity of the entire system and dynamics of technology development and adoption. To better understand the dynamics of gasoline tax effect, a systematic approach is needed.

System Dynamics is a method to enhance learning in complex systems. It helps us learn about dynamic complexity, understand the sources of policy resistance, and design more effective policies. It is fundamentally interdisciplinary. Because we are concerned with the behavior of complex systems, system dynamics is grounded in the theory of nonlinear dynamics and feedback control developed in mathematics, physics, and engineering (Sterman 2001).

System Dynamics has been used to analyze energy problems, taxation and auto development ever since, but few studies explore the role of gasoline tax in the process of fuel economy technology improvement. Given gasoline tax and pressure from high gasoline price, consumers may tend to purchase better fuel efficiency car at least for the same price range, hence encourage automakers to improve its technology development and adoption, reducing the overall fuel economy of cars on road.

Due to time limitation, a country-specific model will be created on the basis of China's private passenger vehicle market which is the main segment of the automobile market and a large consumer of gasoline. These simplifications can be relaxed in later research.

To gain insight of the dynamics, we disaggregate the car stock into seven categories according to its price. In each category, we separate them into fuel efficient car and non-fuel efficient car with their relative level of average fuel economy in that price range. Referring to the relative income hypothesis, households are divided into several income classes related to the car price.

We apply historical data for the years before 2007 and run the model to see why the average fuel economy is not improving as expected in the past few years. For the years after 2007, we assume three different scenarios – the first one is that the gasoline price stays constant after 2007; the second one encounters a step increase to double the price in 2015; and the third one follows a linear gradual increase to twice of gasoline price from 2007 to 2015.

Average fuel economy, total gasoline consumption and cost per vehicle kilometers (v-km) are the main indexes to analyze the effect of gasoline tax in all the scenarios. Different timing of policy implementation, tax refund and technology

development subsidy from tax collection are tested and compared.

The damage from the tax imposition when the gasoline price stays constant since 2007 is analyzed first. If the gasoline price does not rise at all, the gasoline tax could make some damage to car owners, but probably not as much as most of us expect.

When the gasoline price increases, the sooner we impose the gasoline tax, the better. Even though we face a cost increase right after the tax imposition, we can enjoy a much lower cost later and cover the cost increase before. Taking the tax as subsidy for technology development of fuel economy, a much better benefit can be enjoyed.

This thesis is organized in eight chapters. Chapter 2 summarizes the related literature and past work for the problem under study. Chapter 3 states the problem in details and Chapter 4 develops the dynamic hypothesis through causal loop diagram. Chapter 5 introduces the main structure of system dynamic modeling by stock and flow diagram. Following Chapter 6 focuses on the validation of the model by various testing methods such as boundary adequacy, structure assessment, dimensional consistency, extreme condition test and sensitivity test. Chapter 7 conducts behavior analysis and policy design, attempting to understand the dynamics behind the gasoline consumption problem and try to analyze the effect of gasoline tax on consumers' and automakers' behavior. The last Chapter 8 concludes the major findings and results of the current study, and points out its limitation and necessary future work.

Chapter 2 Literature Review

Time-series analysis and cross-sectional analysis are probably two popular ways to analyze the causal relationships. Time-series analysis examines variables over time, such as the effects of population growth on a nation's GDP. Cross-sectional analysis examines the relationship between different variables at a point in time; for instance, the relationship between individuals' income and food expenditures.

A strong tendency in these studies is to correlate factors in light of the historical data, neglecting the feedback loops among them. Such simplistic attributions fail to consider the entire system and do not appreciate the complexity of system. Additionally, some may only consider the end states, with little consideration given to the dynamics that would lead to realizing these end states.

System Dynamics is an approach to understand the behavior of complex systems over time. It deals with internal feedback loops and time delays that affect the behavior of the entire system. The use of feedback loops and stocks & flows help describe how even seemingly simple systems display baffling nonlinearity and that makes System Dynamics stand out from the other approaches dealing with complex systems.

System dynamics modeling has been used for strategic energy planning and policy analysis for more than twenty-five years. The story begins with the WORLD modeling projects conducted in the early 1970s by the System Dynamics Group at the Massachusetts Institute of Technology.

One of the central assumptions underlying the WORLD models is that the earth's natural resources are, at some level, finite and that the exponential growth in their use could ultimately lead to their depletion and hence, to limit global population and economic growth (F. Naill, 1992).

The finite resources assumption, put forth by petroleum geologist M. King Hubbert (1949), tells that the life cycle of oil and gas discovery and production yields a bell-shaped production curve. That curve describes "a period of low resource price

and exponential growth in production, a peaking of production as the effects of resource depletion cause discoveries per foot of exploratory drilling to drop and resource price to rise, in addition to a long period of rising costs and declining production as the substitution to alternative resources proceeds”.

Worried about problems suggested in the Limits to Growth (Meadow et al. 1972) from the dependence on oil, the National Science Foundation of the United States asked the Resource Policy Group at Dartmouth College to study the United States’ “energy transition problem”. One of the results from using FOSSIL1 to analyze the energy transition questions was that: Smoothly passing through the energy transition requires policies that both stabilize energy demand and increase alternative energy supplies.

During his work to modify and extend the FOSSIL1 model into the FOSSIL2 model, John Sterman realized that the FOSSIL2 model ignored important feedbacks and interactions between the energy sector of the economy and the economy itself. For his Ph.D. dissertation, Sterman built a system dynamics energy model that captured, for the first time, significant energy-economy interactions. The model pointed out the following conclusions: As OPEC prices rise, the costs of producing synthetic fuels and other alternative sources rise, adding to inflationary pressures. The economy is likely to face a prolonged period of economic vulnerability due to continuing depletion of nonrenewable resources, slow development of alternative sources, and lags in the adjustment of energy consumption to higher prices (Sterman 1981).

Later on, Fiddaman (1997) created a new climate-economy system dynamics model called FREE (Feedback-Rich Energy Economy model). The FREE model explicitly incorporates the dynamics of oil and gas depletion as a “source constraint” on the energy-economy system (as do all of its system dynamics predecessors), as well as the dynamics of a “sink constraint” (i.e., climate change) on the energy-economy system.

Pressure from human induced climate-change and fossil fuel limitation urge the process of energy conservation and energy transition. Due to the close relationship

between the automotive and energy industry, gasoline conservation is now at the top of the agenda.

The M3 model, a Millennium Institute and General Motors collaboration, is a system dynamics model for analysis of vehicle markets in emerging markets (Weishuang Qu et al. 2003). It emphasizes the interconnectedness of the economy, demographics, the vehicle market, regulatory policies, infrastructure, energy demands, emissions, congestion, international trade, and other factors. However, the representation of fuel efficiency and technology investment is not fully developed in the current M3 model.

The government can influence the behavior of automakers through regulation, tax and subsidy, but its role in the gasoline conservation is under discussion. This paper is going to explore the effect of government's gasoline taxation policy, aiming to prompt manufactures to develop and adopt technology, improve fuel economy, reduce total gasoline consumption while reducing or maintaining consumer cost per vehicle kilometers. We aggregate all kinds of auto manufactures into one big party, ignoring competitions inside the auto industry.

Chapter 3 Problem Statement

Gasoline conservation is forced by a shortage or depletion of oil resources. As the transportation sector is the major consumer of oil products, its energy conservation receives the most attention. However, while it offers many long-term socio-economic advantages, there is not enough incentive for manufactures to invest more on technology and develop better fuel-efficient cars. It may be difficult for car owners and automakers to justify investment in some gasoline saving measures. Financial payback versus energy savings argument is always made.

The increase in purchasing power in China has led to a growing demand for quality transportation services and more convenient and flexible transportation systems. Use of private cars is often the preferred choice of wealthy people and the middle class. Increase in the use of private vehicles is largely the result of government policy to promote economic development through automobile sector growth and infrastructure development. It puts emphasis on the increased private car ownership as means of stimulating personal consumption for economic growth (Gan 2003).

Rapid development of private passenger car ownership in China has had considerable impacts on energy use by increasing the pressure on oil production, distribution and consumption as the country becomes increasingly dependent on imported oil to sustain its growing demands. Market competition has always been a major driving force behind improving the energy efficiency of newly made cars. However, in terms of fuel economy, cars in China consume somewhat 10%-15% more energy than those products in developed countries.

Realizing the inefficiency of market, the China government imposed a stricter fuel economy regulation for passenger cars in 2004, aiming to improve fuel efficiency of cars on the market and product line. Unfortunately, we did not see further improvement except automakers narrowly meeting the fuel economy standard, reluctant to do things better. The average fuel economy on road is still unexpectedly increasing. According to this, we draw our reference mode for the problem below.

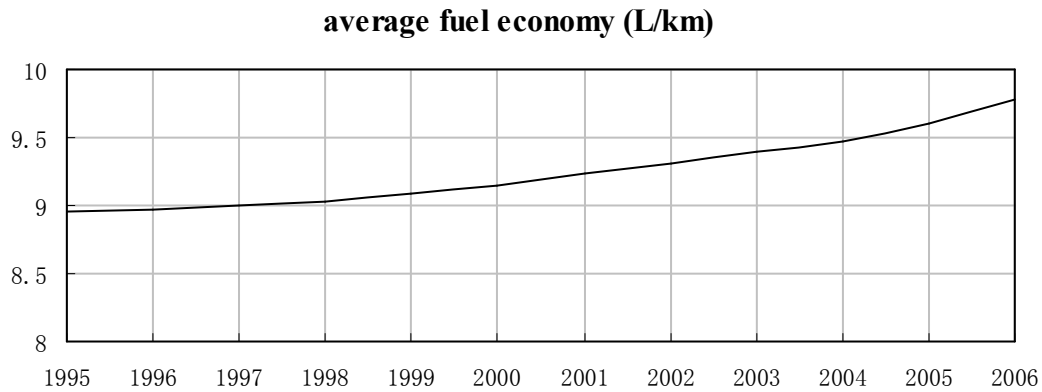


Figure 3-1 Problem Reference Mode

What's more, the market saw advocates for economy cars but few really take actions. Some may attribute this to people's preference for bigger cars with increasing buying power. The rising gasoline price urges consumers to concern about fuel economy. People are hesitant to turn to small or economy cars, which always remind them of poor looking, low social status etc. Without the market incentive, namely profit, the technology development and adoption in auto industry is very slow.

The China government is considering some additional policies such as gasoline tax besides fuel economy standard extension to freight vehicles. Therefore, understanding the dynamics of this problem is helpful when policy makers are making decisions.

Chapter 4 Dynamic Hypothesis

Feedback is one of the core concepts of system dynamics. Yet our mental models often fail to include the critical feedbacks determining the dynamics of our systems. In system dynamics we use several diagramming tools to capture the structure of systems, including causal loop diagrams and stock and flow maps.

Causal loop diagrams (CLDs) are an important tool for representing the feedback structure of systems. Long used in academic work, and increasingly common in business, CLDs are excellent for

- Quickly capturing our hypotheses about the causes of dynamics;
- Eliciting and capturing the mental models of individuals or teams;
- Communicating the important feedbacks we believe are responsible for a problem.

A causal diagram consists of variables connected by arrows denoting the causal influences among variables. The arrows with two lines denote some delays between two linked variables. The important feedback loops are also identified in the diagram. Each causal link is assigned a polarity, either positive (+) or negative (-) to indicate how the dependent variable changes when the independent variable changes. The important loops are highlighted by a loop identifier which shows whether the loop is a positive (reinforcing) or negative (balancing) feedback. Note that the loop identifier circulates in the same direction as the loop to which it corresponds.

The following Causal Loop Diagram (see Figure 4-1) represents my very basic hypothesis of the problem.

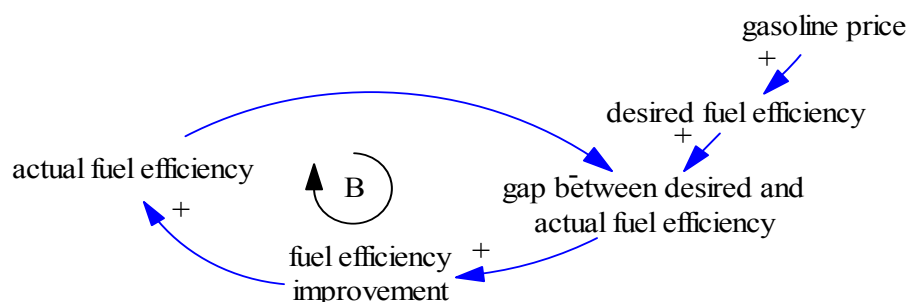


Figure 4-1 Basic Hypothesis – CLD

When the gasoline price goes up, people will desire higher fuel efficiency - and will choose from existing models - thus closing the gap between desired and actual efficiency (a balancing loop). Consumers cannot directly change the actual fuel efficiency but to make auto manufactures to improve it through market information.

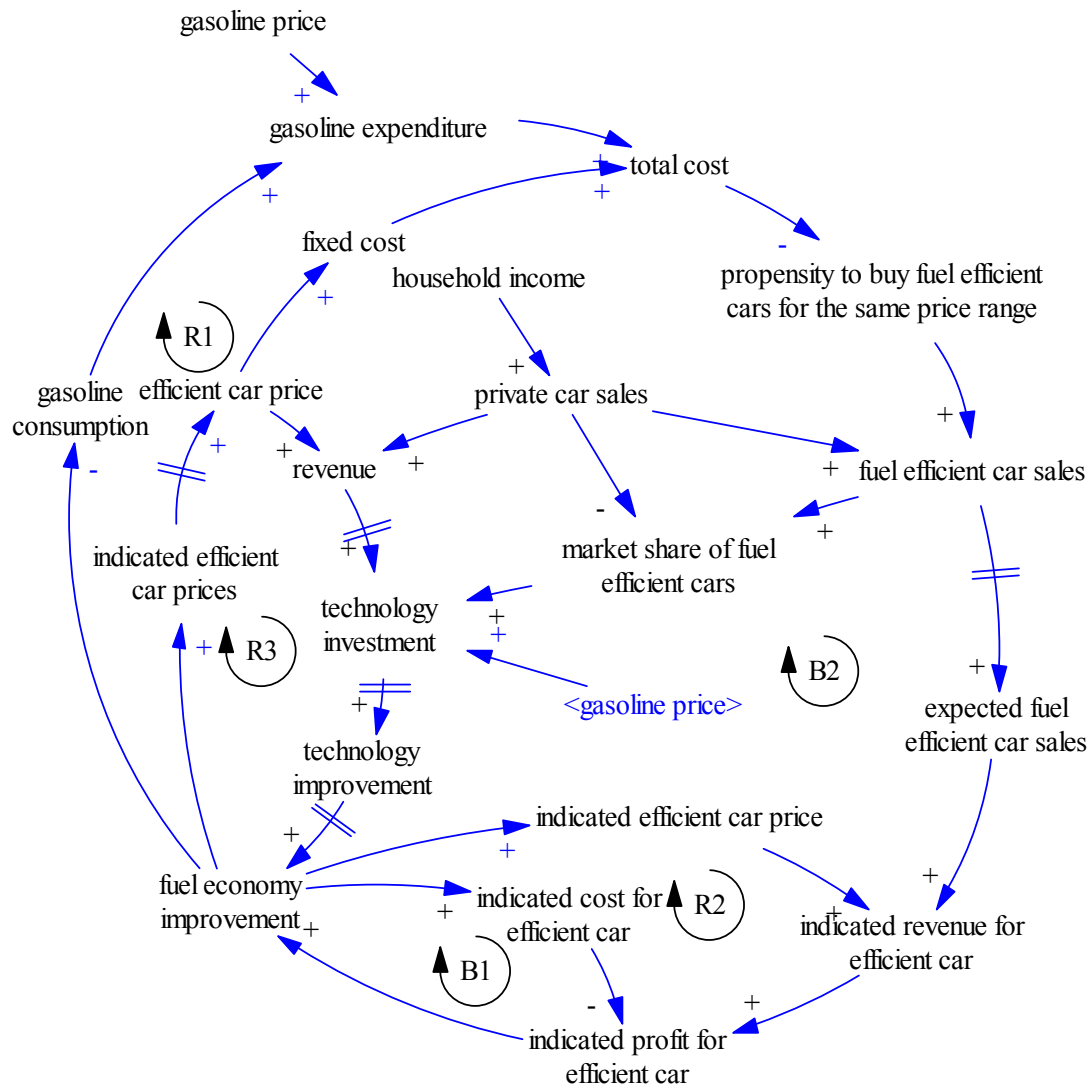


Figure 4-2 Elaborate Hypothesis – CLD

Reinforcing Loop 1: Effect of gasoline expenditure

The increase in disposable household income leads to increase in private car sales. Among all the cars on the market, some of them are more fuel efficient than the others within the same price range. Fuel efficient cars can reduce the fuel consumption to reduce gasoline expenditure. With the continual climb in gasoline price, more and more consumers tend to buy cars with better fuel efficiency. Seeing this trend on the

market, automakers are considering adopting technology to improve its fuel economy on the product line. If the profit is large enough, they will begin their process of fuel economy improvement.

Reinforcing Loop 2: Effect of car price on automakers

On one hand, this adoption entitles a higher markup in car price due to its better fuel efficiency than average in the same price range. It will increase their revenue and possibly increase their profit, which can be a strong incentive for further fuel improvement.

Balancing Loop 1: Effect of fuel consumption improvement on automakers

On the other hand, fuel economy development on product line causes product transition cost such as retrofit or substitute cost, which may reduce the indicated profit.

If the revenue is larger than the cost, manufactures would apply the technology on product line and better fuel efficient cars appear on the market after some delay.

Reinforcing Loop 3: Technology development

In addition to production changes, auto manufactures would like to invest more in technology development given expanding market share of better fuel efficiency cars and increasing revenue. However, technology development and adoption can be seen only after some delay time, not immediately after the investment.

Balancing Loop 2: Effect of car price on consumers

Nevertheless, as fuel efficient cars charge more than the 'normal' cars, consumers' fixed cost increases, making consumers reluctant to buy better fuel efficient cars for the same price range. This decreases fuel efficient car sales and make automakers hesitant to invest in technology development and adoption.

As we can see, consumers' cost is determined by fixed cost and variable cost, which is mainly car price and gasoline expenditure respectively in our current model. The improvement of fuel consumption can reduce the gasoline expenditure and this reduction may cover the cost increased by the car price. Thus, the cost is decided by the reinforcing loop 1 (R1) and the balancing loop 2 (B2). Whether it would increase

or decrease is determined by the dominance of the loop.

Further, auto manufactures' decisions are largely influenced by consumers' preference and the profit calculation. Interestingly, the profit is also decided by one reinforcing loop (R2) and one balancing loop (B2). This means the increasing cost does not necessarily lead to decreasing profit given enough revenue from the increasing sales. Similarly, the increasing revenue does not necessarily cause increasing profit due to more strong effect from increasing cost. The shifting dominance can get very different result.

Chapter 5 Model Description

5.1 Model Boundary

To gain intuition into the gasoline conservation, a quantitative, integrative, dynamic model with a suitable boundary and time horizon, and realistic representation of decision making by individuals and other key actors is essential. The time horizon of the model is from 1995 to 2030, long enough to capture the delayed and indirect effects of potential policies. Due to time limitation, only the private passenger vehicles in China are considered and it is the main segment of the vehicle market. We target the mass market of typical consumers rather than fleets.

Gasoline consumption is determined by the interplay of several endogenous factors, such as consumers' propensity to buy better fuel efficiency cars, automakers' willingness to improve fuel efficiency in the lab or on the product line, and government incentives.

The model boundary chart summarizes the scope of the model by listing which key variables are included endogenously, which are exogenous, and which are excluded from the model.

Table 5-1 Model Boundary Chart for Key Variables

<i>Endogenous</i>	<i>Exogenous</i>	<i>Excluded</i>
Private Car Ownership	Gasoline Price before Tax	Car Production
Fuel Economy	Tax Rates	Car Imports and Exports
Technology Investment	Population	
Car Price	Disposable Income	
Gasoline Consumption		
Purchase Preference		
Investment Preference		

5.2 Major Assumptions

5.2.1 Relative Income Hypothesis

Relative Income Hypothesis was developed by James Stemble Duesenberry (1949). His analysis is based on two hypotheses. The first hypothesis is with respect to the consumption behavior of an individual. It states that the consumption behaviors of individuals are interdependent. An individual is not so much concerned with his absolute level of consumption as he is with his consumption relative to the rest of the population. Thus the percentage of income consumed by an individual depends on his percentile position in the income distribution. The second hypothesis states that the present consumption is not influenced merely by present levels of absolute and relative income, but also by levels of consumption attained in previous period. He argues that consumption relations are irreversible over time. It is difficult for a family to reduce a level of consumption once attained. The aggregate ratio of consumption to income is assumed to depend on the level of present income relative to past peak income.

According to this hypothesis, the disposable income per household is highly related to their car purchasing behavior. People in certain income class would like to buy cars in certain price range. To make it simple, we assume that the cars people buying are priced at the same level of their disposable income per household. That is if they have an income of 50,000 to 100,000, then they only buy the car at the price of 50,000 to 100,000. Once the income becomes 100,001, they can buy the car at the higher price level. This assumption sounds too strict to be true in everyday life because we may buy the car pricing over 100,000 even we have an income of 80,000, while on the other hand we may buy cars under the price of 100,000 even we have the disposable income more than that. From this point of view, we may say that the population buying cars above their income level and those buying cars below their level are equal. Therefore they offset each other and the end effect remains the same as was described in the previous text. We may relax this assumption in later research.

At this point, we divided all the people in seven income classes, i.e. lower than

50K, 50K to 100K, 100K to 160K, 160K to 230K, 230K to 300K, 300K to 500K, and over 500K, with respect to some car price categorization.

5.2.2 Multinomial Logit Model

To describe consumer's propensity to purchase better fuel efficiency car for the same price range and automakers' willingness to change fuel economy of new cars, we apply the multinomial logit model.

The neoclassical economic theory assumes that each decision-maker is able to compare two alternatives a and b in the choice set C using a preference-indifference operator \succeq . It results that using the preference-indifference operator to make a choice is equivalent to assigning a value, called utility, to each alternative, and selecting the alternative associated with the highest utility. However, this theory fails to explicitly capture some level of uncertainty in human behavior.

An important characteristic of models dealing with uncertainty is that, instead of identifying one alternative as the chosen option, they assign to each alternative probability to be chosen. Luce (1959) proposed the choice axiom to characterize a choice probability law by models with stochastic decision rules. Random Utility Models, based on the deterministic decision rules from neoclassical economic theory, capture uncertainty by random variables representing utilities.

The assumption of the deterministic term is that, the utility of each alternative must be a function of the attributes of the alternative itself and of the decision-maker. The logit model is derived from the assumption that the error terms of the utility functions are independent and identically Gumbel distributed. These models were first introduced in the context of binary choice models, where the logistic distribution is used to derive the probability. Their generalization to more than two alternatives is referred to as multinomial logit models. The derivation of this result is attributed to Holman and Marley by Luce and Suppes (1965). It is interesting to note that the multinomial logit model can also be derived from the choice axiom defined by Luce (1959).

We give a popular description of this model before we turn to its properties. Take

automakers' choice for example, for the individual investment, the choice is typically one or another of the options. The model assumes that the individual auto manufacture chooses the most profitable alternative. This is illustrated by the straight line in Figure 5-1 below. When the total profit resulting from changing fuel economy are higher than the profit without changing fuel economy, new cars with expected fuel economy will be produced on the product line, and vice versa.

The fact that different auto manufactures face different total profits implies that the automakers as a whole behave differently from the individual automaker. Not all automakers will suddenly shift from current fuel economy to expected fuel economy when the profit of expected fuel economy increases slightly above the other. Some of the automakers still find current fuel economy to be the more profitable alternative. The smooth and curved lines in Figure 5-1 below show how the auto industry is gradually changing its fuel economy, given consideration of consumer preference and relative profitability. This is a less rigid view of the substitution process than what is implied by the popular assertion that change in fuel economy for new car production is either competitive or not competitive.

Willingness to Change Fuel Economy

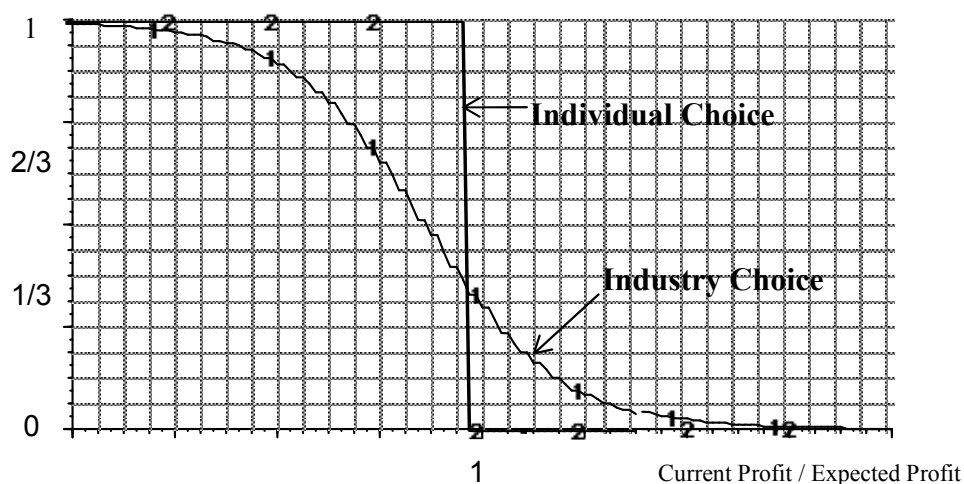


Figure 5-1 Willingness to Change Fuel Economy as a Function of Profit from Current Fuel Economy Car and Expected Fuel Economy Car

The multinomial logit model (MNL) for automakers' willingness to change fuel economy W_i is shown in equation 1:

$$W_i = \frac{e^{\alpha P_i}}{\sum_j e^{\alpha P_j}} \quad (1)$$

The MNL has only one parameter α , except for the parameters profits. When profits are given, α determines the steepness of the curve in Figure 5-1. When α is at a high extreme the function mimics the individual choice. In the MNL the sum of willingness always add up to 1. When both of the profits are equal, half of the auto manufactures are willing to change fuel economy. If we divide numerator and denominator of the logit function by $\exp(\alpha P_i)$, we see that willingness depends on profit differences (Moxnes 1990).

The reasoning for customers' propensity to buy better fuel efficiency car for the same price range is more or less the same as the above. The propensity relies on the cost differences. However, the propensity changes in reverse direction to the total cost changes. The higher the cost, the lower percentage of people tends to buy better fuel efficiency cars. Consequently, the MNL model for this variable Propensity in equation 2 changes a little bit from the one expressing W_i , which changes in the same directions as total profit changes.

$$P_i = \frac{e^{-\alpha C_i}}{\sum_j e^{-\alpha C_j}} \quad (2)$$

5.3 Model Structure

5.3.1 Stocks and Flows Diagram

Causal loop diagrams are very useful in many situations. They are well suited to represent interdependencies and feedback processes. However, causal loop diagrams suffer from a number of limitations and can easily be abused. One of the most important limitations of causal diagrams is their inability to capture the stock and flow structure of systems. Stocks and flows, along with feedback, are the two central concepts of dynamic systems theory.

Stocks are accumulations. They characterize the state of the system and generate

the information upon which decisions and actions are based. Stocks give systems inertia and provide them with memory. Stocks create delays by accumulating the difference between the inflow to a process and its outflow. By decoupling rates of flow, stocks are the source of disequilibrium dynamics in systems. Stocks are altered by inflows and outflows. In the following, we use stock and flow map to describe the model structure.

5.3.2 Private Car Ownership

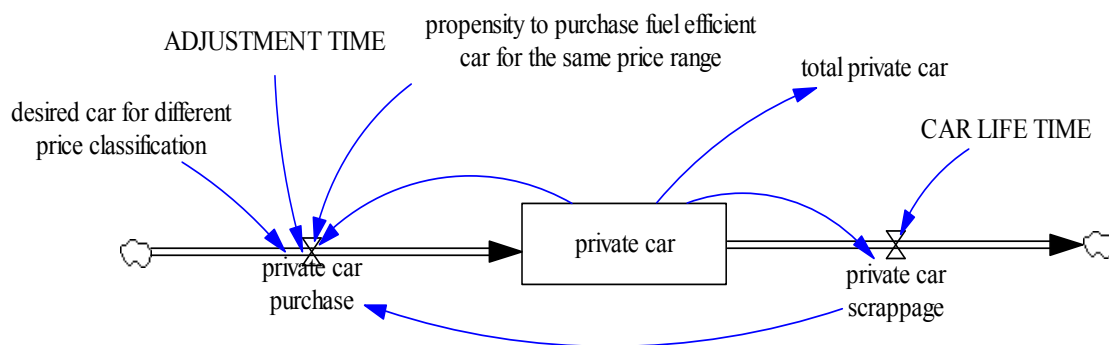


Figure 5-2 Structure - Private Car Ownership

The private car ownership increases by new car purchase and decreases by old car scrappage. The private car purchase is determined by the gap of actual and desired private car ownership which is divided into seven categories according to disposable income per household and car price. The desired private car ownership is the product of number of household and desired car per household, a table function from a consumer survey. The adjustment time is time for people to collect car information and make the buying decisions. Besides the adjustment of the gap, the scrapping car adds to the private car purchase as well.

In each category, the car is named 'fuel efficient car' if its fuel economy is better than the average in that category, and the other is called 'non fuel efficient car' relatively. Considering the gasoline price and car price, some people prefer to buy 'fuel efficient car' within their range. Hence, the purchase is further split into two parts in each category.

5.3.3 Technology Investment

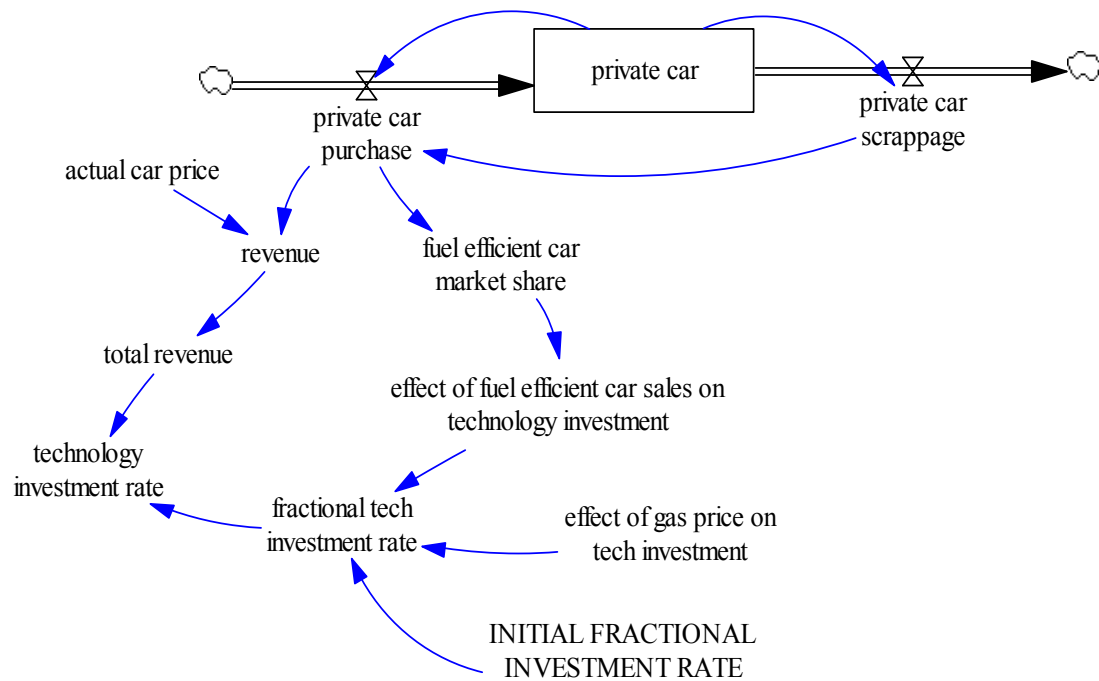


Figure 5-3 Structure – Technology Investment

The total ‘fuel-efficient car’ bought over total car purchase constitutes the fuel efficient car market share. This market share has a positive effect on fractional technology investment rate. When the market share is increasing, auto manufacturers would like to invest more in technology in order to improve fuel economy to earn more money. Besides, the gasoline price also has a positive effect on technology investment. The higher gasoline price drives people to consider more on fuel economy, thus automakers have to improve their fuel economy technology to catch up with consumers’ needs.

5.3.4 Fuel Economy Development

Fuel economy development goes through three different stages, i.e. fuel economy of prototype, new cars and cars on road. To make it simple, the fuel economy changes are represented by ‘relative fuel economy’, a relative improvement compared to the initial fuel economy. So the new fuel economy is the product of initial value and relative level. We would explain these three stages separately below.

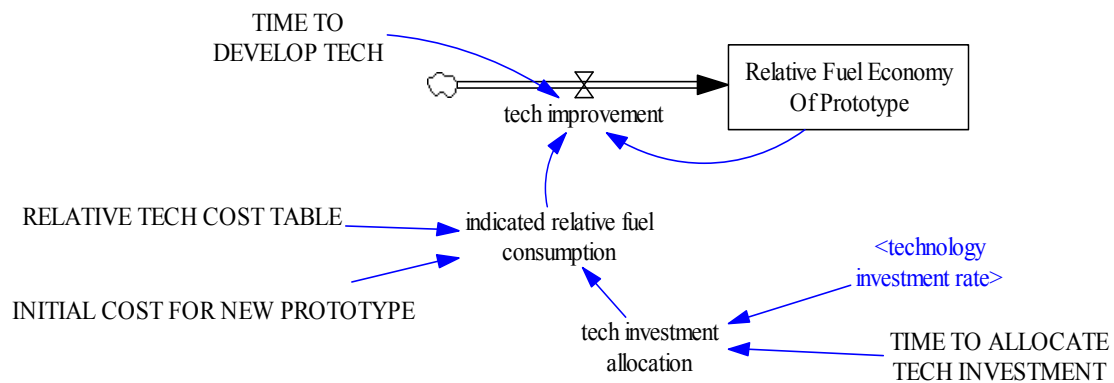
Stage 1: relative fuel economy of prototype

Figure 5-4 Structure – Fuel Economy of Prototype

The money for technology development is allocated to the right place after some time. At the beginning, it is much easier to improve fuel economy. As the technology level becomes higher and higher, it demands more money than ever to improve just as the same little as before. The relative tech cost table represents the relationship between relative tech improvement and money requirement. With certain money allocated to technology development, we get one and only one indicated relative level of fuel economy.

Delays are pervasive. It takes time to measure and report information. It takes time to make decisions. And it takes time for decisions to affect the state of a system. The technology development happens some time after the technology investment. Here the delay represents the gradual improvement of fuel economy. The negative feedback loop here acts to bring the state of the system in line with the indicated state. The state of the relative fuel economy of prototype is compared to the indicated state. If there is a discrepancy between the indicated and actual state, corrective action is initiated to bring the state of the system back in line with the indicated state. Moreover, we use a min function to make sure the technology level would not go back even if we invest too little. Little money can be used to maintain the routine operation in the research and development department. Therefore, the equation for fuel economy improvement is as follows:

$$\text{Tech improvement} = \text{MIN} (0, (\text{indicated relative fuel consumption} - \text{Relative Fuel Economy Of Prototype})) / \text{TIME TO DEVELOP TECH}$$

Stage 2: relative fuel economy of new car

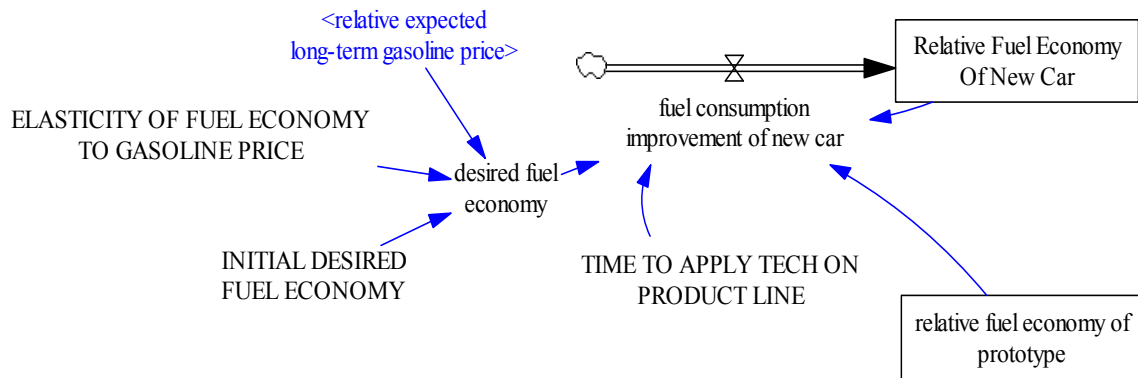


Figure 5-5 Structure – Fuel Economy of New Car

Considering the long-term gasoline price development and consumers’ desired fuel economy, auto manufacturers do not necessarily apply the latest technology on the product line. Instead, they put more weight on consumers’ desire, because they may earn more profit by selling more cars. In terms of liters per 100 kilometers, if the desired fuel economy is lower than the technology level, they adopt the technology on product line. Otherwise, they keep on producing what consumers need. Thus, we know that the fuel economy improvement is highly constrained by consumers demand and their gasoline price expectation.

Stage 3: average fuel economy on road

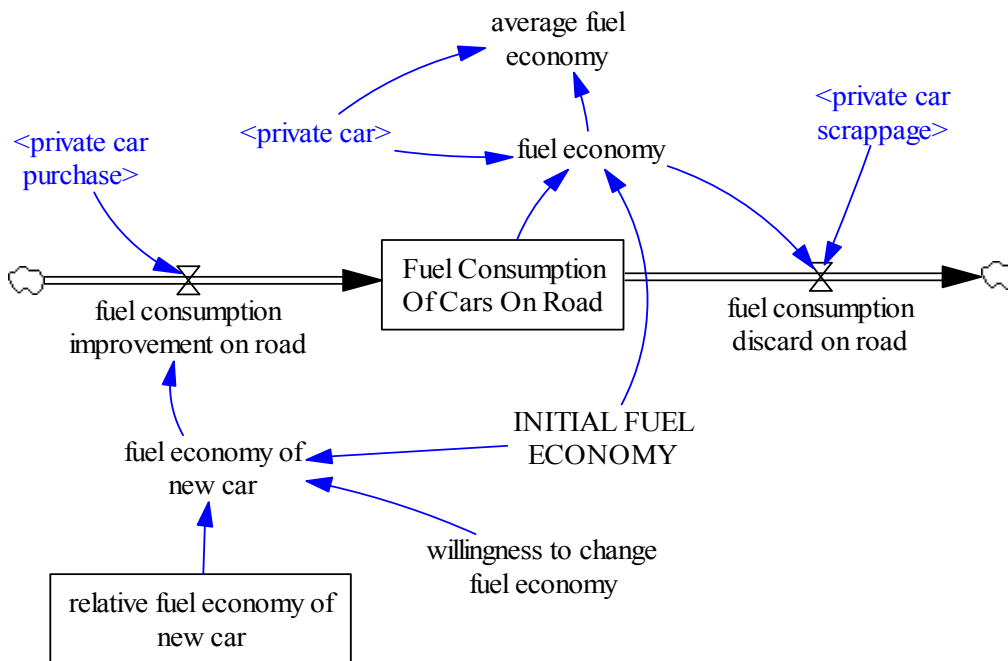


Figure 5-6 Structure – Average Fuel Economy on Road

Provided expected demand for ‘fuel efficient car’ and ‘non-fuel efficient car’ in each category, indicated car price and substitute cost, some automakers change their fuel economy of new car, some do not. This is expressed in the term of ‘willingness to change fuel economy’, a subscript for different car categories.

The fuel economy of cars on road improves by the inflow of new car with good fuel economy and the outflow of old car with poor fuel economy. Average fuel economy denotes the overall improvement or deterioration of car fuel economy on road, regardless its category. It is a comprehensive index to evaluate the state of gasoline consumption for a hundred kilometers per car.

5.3.5 Cost and Consumption

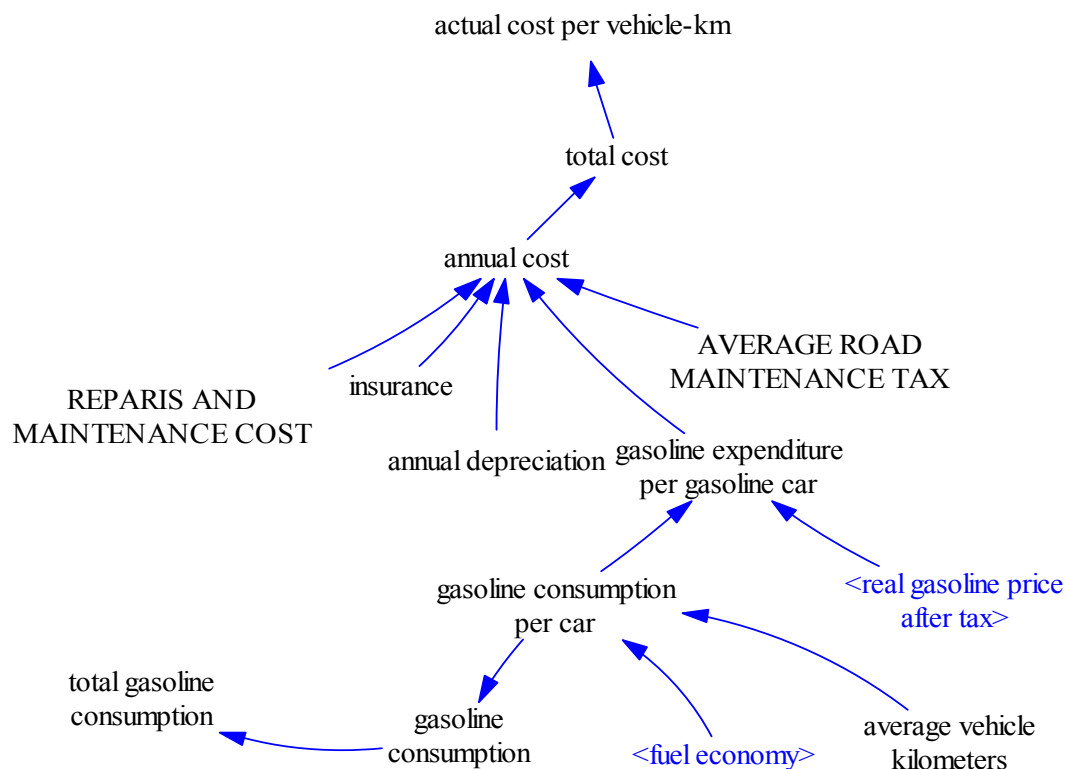


Figure 5-7 Structure – Cost and Gasoline Consumption

At this point, it must be noted that only main costs – repairs and maintenance cost, insurance, annual depreciation, average road maintenance tax and gasoline expenditure- are calculated in the model. The gasoline consumption is the product of fuel economy and the average vehicle kilometers. Total gasoline consumption here sums up separate consumption from different car categories.

Chapter 6 Model Testing

6.1 Model Testing Overview

Many modelers speak of model “validation” or claim to have “verified” a model. In fact, validation and verification of models is impossible because all models are wrong. All models, mental or formal, are limited, simplified representation of the real world. They differ from reality in ways large and small, infinite in number (Sterman 2000). Instead of seeking a single test of validity models either pass or fail, we try to seek multiple points of contact between the model and reality by drawing on many sources of data and a wide range of tests. Instead of viewing validation as a testing step after a model is completed, we focus the client on the limitations of the model so it can be improved and so clients will not misuse it. Tests we are using here include boundary adequacy test, structure assessment test, dimensional consistency test, parameter assessment test, extreme conditions test and sensitivity analysis test.

6.2 Boundary Adequacy Test

Boundary adequacy tests assess the appropriateness of the model boundary for the purpose at hand.

Transportation is the main consumer of synthetic oil product and road transport contributes the biggest part to gasoline consumption. However, even in road transport, freight traffic and passenger traffic shows very different characteristics in gasoline consumption, needless to say private or public ownership. To understand gasoline tax effect step by step, in the current model we choose to focus on private passenger car market. Private car market is a booming market in China. As people’s buying power is stronger and stronger, private car sales continue to rise dramatically. Different from fleet, the typical consumers have more freedom to make their decisions. These consumers are more easily to be affected by any policy because they have less

tolerance than fleet owners who are normally public well-financed company. Therefore, it is suitable to limit us to the private car market for the purpose at this point.

Gasoline consumption is determined by car ownership, average vehicle kilometers traveled per year and fuel economy of cars. These three key factors are endogenous in the model to help understand the complexity of dynamic system. The interaction in fuel economy technology development and adoption is captured in the model. Interaction between consumers' purchase preference and automakers' investment preference is included in the model as well.

To make it simple, it is reasonable for us to exclude car production and import & export in the model and make the assumption that the desired private ownership is always fulfilled by either way from the supply side. Furthermore, we are not certain how the gasoline price will develop even we believe that it is highly likely to increase along the way. Hence, gasoline price is used as exogenous variable and changed in different scenarios to analyze possible future development in the model.

In summary, the model has good boundary for our purpose at hand.

6.3 Structure Assessment Test

Structure assessment tests ask whether the model is consistent with knowledge of the real system relevant to the purpose. It focuses on the level of aggregation, the conformance of the model to basic physical realities and the realism of the decision rules for the agents.

A lot of research has revealed that income is the key factor affecting people's car purchasing behavior. Furthermore, the relationship between income and car sales is not linear. When people are very poor, they cannot afford any cars. After they reach the threshold, say 3000 USD per capita in China, we see a dramatically increase in car purchase. However, even we are very rich, the car we need per household is limited, probably two or three. So the desired car ownership shows an S-shape growth in the model.

Moreover, people's consumption behavior is not only constrained by their income but their social status as well. They try to get a car reflecting their status and distinguishing them from a lower class. We split urban and rural population to reflect the uneven income distribution in these regions. In addition, we linked people's income to car price, and divided them into seven different categories to better capture the private car ownership development.

Apparently, cost and benefit are the driving force behind consumers' purchase behavior and automakers' technology investment and adoption behavior. From the economists' view, consumers and automakers should be completely rational human beings. Given the same benefit, consumer would certainly choose to buy the cheaper car – not only cheap in car price but also in its operational cost. Automakers are always pursuing more profit. Nevertheless, in reality, people are not rational enough as economists expect. They face a lot of different situations and they receive either too much or too little information. Even put in front of the same situations, they may make different decisions. The multinomial logit model is used in the current model to reflect this interesting reality.

Last but not the least; we have considered the delays in people's perception, technology investment, technology adoption, fuel economy improvement on road and so on. As far as we can see, the structure of the model conforms to the physical reality and realism of decision rules.

6.4 Dimensional Consistency Test

Dimensional inconsistency may reveal nothing more than a typographical error, an inverted ratio, or missing time constant. More often, units' errors reveal important flaw in the understanding of the structure or decision process we are trying to model.

We always specify the units of measure for each variable as we build our models. Fortunately, the simulation software we are using for system dynamics modeling now include automated dimensional analysis so we can test for dimensional errors with a single command. Our model generates no error messages when we run the

dimensional consistency check. Every equation is dimensionally consistent without the inclusion of arbitrary scaling factors that have no real world meaning.

6.5 Parameter Assessment Test

Limitations on numerical data availability mean it is often impossible to estimate all parameters in a model. In practice, statistical and judgmental methods are used together. Knowledge of the real system constrains the plausible range for many parameters; statistical estimation provides a check on judgmental estimates.

For the current model, we collect data from archival materials, direct experience, professional websites, related literatures and some estimates from authority such United Nations, National Statistical Bureau in China, British Petroleum, State Information Centre of China and so on.

6.6 Extreme Condition Test

Models should be robust in extreme conditions. Robustness under extreme conditions means the model should behave in a realistic fashion no matter how extreme the inputs or policies imposed on it may be. Extreme condition tests ask whether models behave appropriately when the inputs take on extreme values such as zero or infinity. Extreme condition tests can be carried out in two main ways: by direct inspection of the model equations and by simulation.

We have checked the equation along with the structure assessment test and it seems reasonable for us. Following, we check some simulation results when the gasoline price before tax suddenly drops to zero from 2007 until the end of simulation.

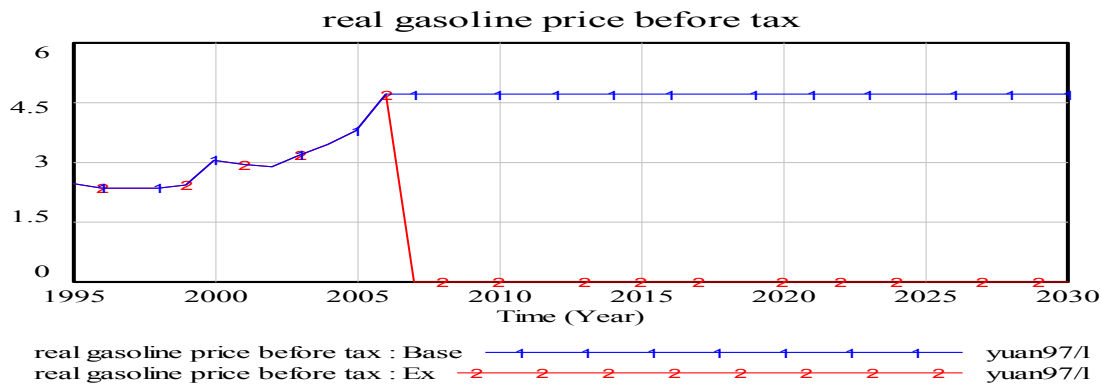


Figure 6-1 Extreme Test – Gasoline Price Zero

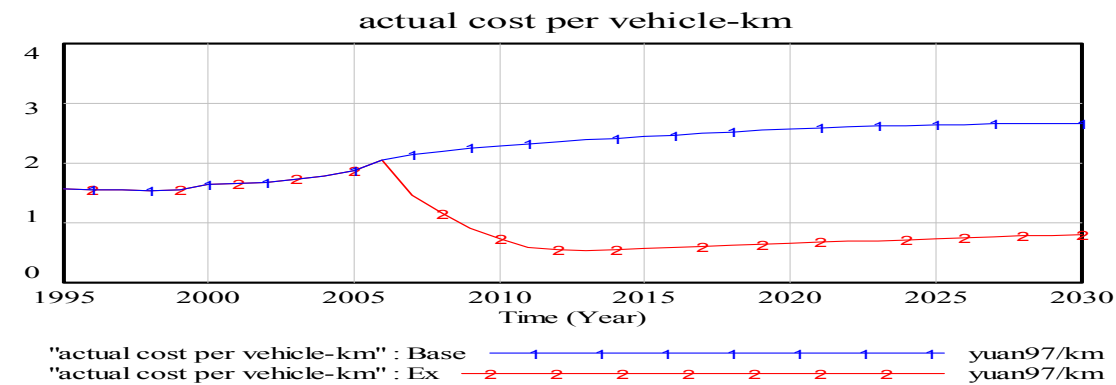
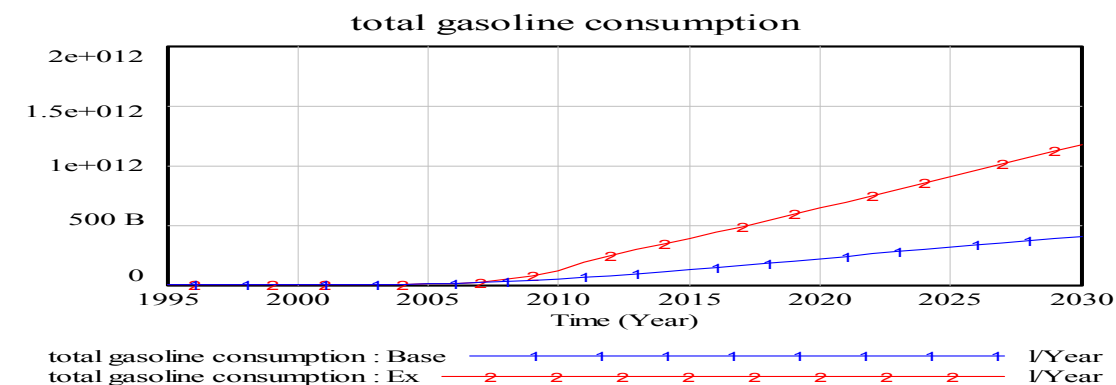
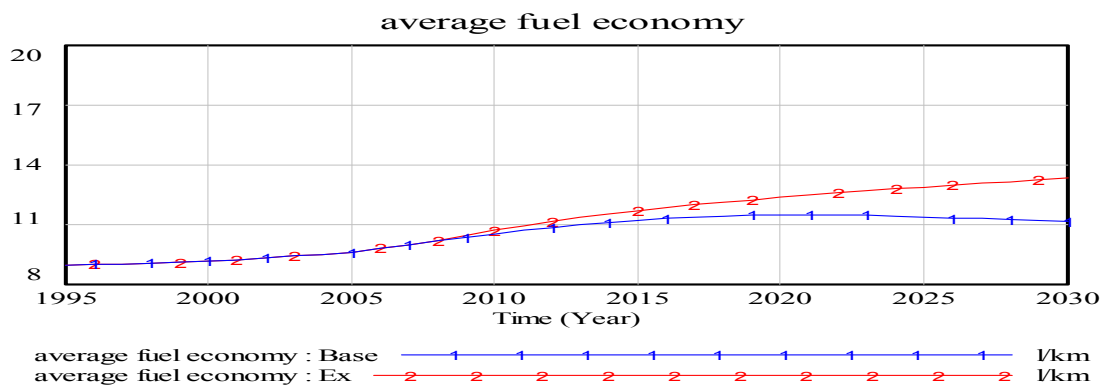


Figure 6-2 Extreme Test Behavior – Gasoline Price Zero

As we do not have any gasoline tax at this point, people can enjoy a free lunch for

gasoline when the price drops to zero after 2007. They can use as much gasoline as they wish and it is totally free. Most consumers may not pay attention to the fuel economy of new cars any more. Some of them may prefer worse fuel economy to enjoy a more powerful engine. As a result, automakers are reluctant to improve the fuel economy as before and some of them even change the fuel economy in a negative way to meet consumers' demand. Thus, we see an increase in fuel economy, which is measured by the liters of gasoline consumed per one hundred kilometers, from 11 liter/100-km to nearly 14 liter/100-km.

In the meantime, the total gasoline consumption reaches 1.17×10^{12} e which is more than double of the number in the base run. The total consumption does not show a dramatically aggressive increase in the extreme condition test because of two main reasons. The first one is that people would just drive some maximum kilometers in one year and no more than that even the gasoline is free. The second one is that auto manufactures would not necessarily turn to worse fuel economy car production due to some cost and benefit concern. With these two limits, the total gasoline consumption would not increase infinitely.

For the actual cost per vehicle kilometer, in stead of staying flat after the drop in gasoline price, the costs see some tiny increase in the simulation. Why? Because consumers have to pay a premium for the car they want. Automakers are willing to do some change to make consumer happy but they certainly put a markup on the car price to make up what it costs. This is consistent with what happens in reality. Consumers would like to pay a little more to get some additional and cool features of the car.

In a word, the simulation results in the extreme conditions test are in line with what we have known in reality.

6.7 Sensitivity Analysis

Since all models are wrong we must test the robustness of our conclusion to uncertainty in our assumptions. Sensitivity analysis asks whether the conclusions

change in ways important to the purpose when assumptions are varied over the plausible range of uncertainty.

There are three types of sensitivity: numerical, behavior mode, and policy sensitivity. Numerical sensitivity exists when a change in assumption changes the numerical values of the results. Behavior mode sensitivity exists when a change in assumptions changes the patterns of behavior generated by the model. Policy sensitivity exists when a change in assumptions reverses the impacts or desirability of a proposed policy.

Given the limited time and resources, sensitivity analysis must focus on those relationships and parameters we suspect are both highly uncertain and likely to be influential. A parameter around which no uncertainty exists need not be tested. Likewise, if a parameter has but little effect on the dynamics it need not be tested even if its value is highly uncertain because estimation errors are of little consequence. In the following part of text, we show the model sensitivity to economy growth rate, desired ownership rate and relative technology cost.

6.7.1 Economy Growth Rate

The economy in China has kept on increasing for a few years. It is predicted by some economists that it will continue to grow on an average rate of 7% per year to the year 2030. As the economy becomes more mature, it is possible that our economy growth will slow down. Will it affect the general behavior for the problem we are dealing with? To get an insight, we test three different economy growth rates here. From year 2007, the economy growth rate is set to be 2% lower (Eco1), equal to (Base) and 2% higher (Eco2) than the average growth rate from 1995 to 2006, 5.5% for rural area and 7.5% for urban area.

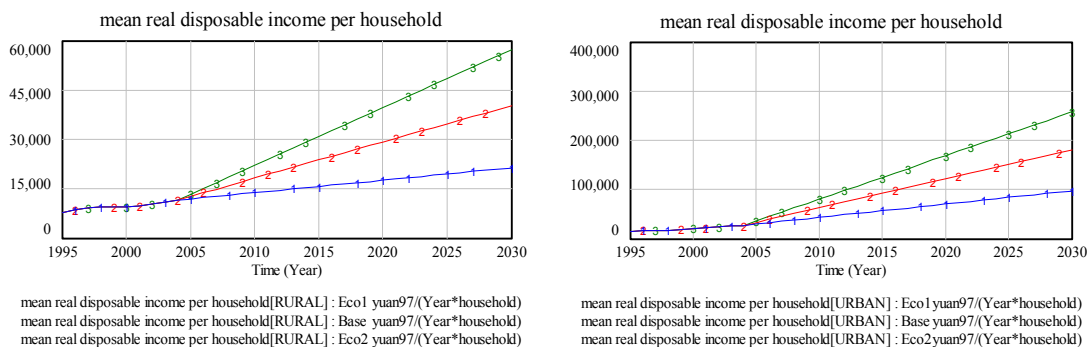
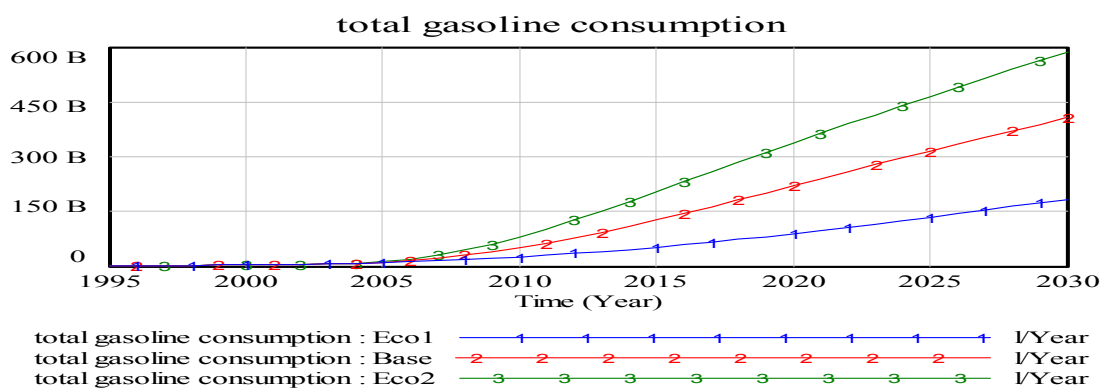
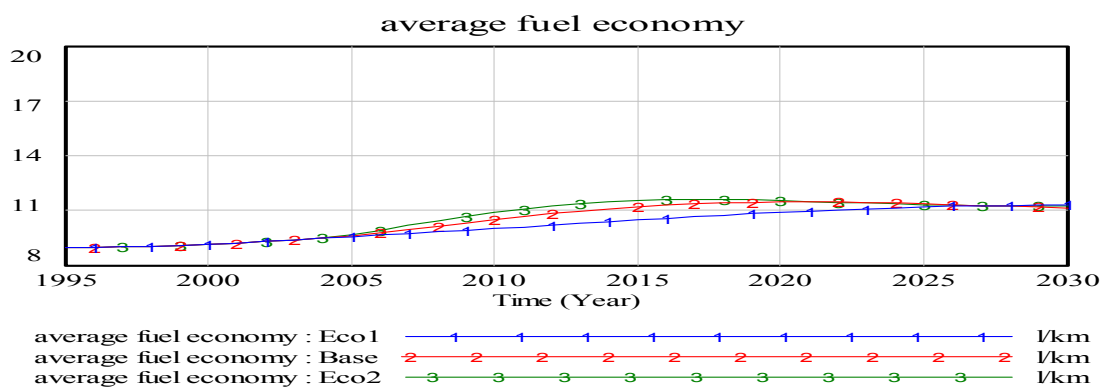
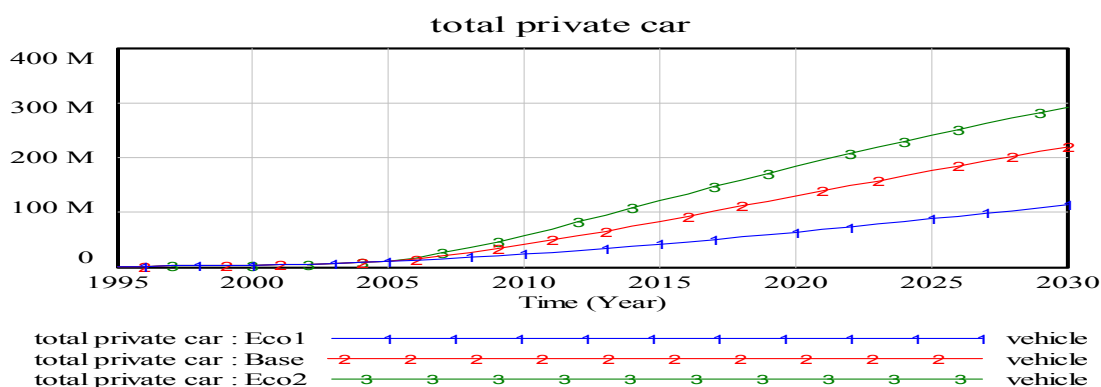


Figure 6-3 Different Economy Growth Rate



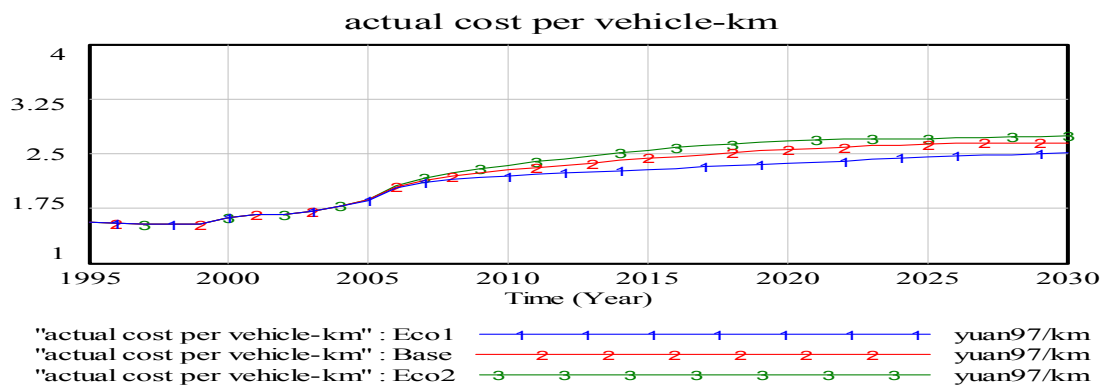


Figure 6-4 Sensitivity Behavior - Different Economy Growth Rate

The variation in the economy growth rate does not result in behavioral changes in the key variables as can be observed in Figure 6-4. The higher growth rate leads to more total private car ownership, greater total gasoline consumptions and higher cost per vehicle kilometer. In the case of average fuel economy, all of them show the behavior of overshoot before reaching equilibrium. However, it peaks earlier at a higher point when the economy growth rate is higher. These behaviors are consistent with what we have known about the reality.

6.7.2 Desired Private Ownership per Household

The desired private ownership per household table we are using contains adjusted data from a survey held by State Information Centre of China. People tend to be overconfident in their judgments. Judgmental parameter estimates are likely to be more uncertain than people's intuitive confidence bounds suggest. Overconfidence also arises when parameters are estimated statistically. Given the uncertainty and nuisances in the survey, we adjust the desired private ownership in two opposite directions from the original one to check its influence on the pattern of model behavior. With the same income level, Do1 has fewer cars per household than Base, which has fewer than Do2.

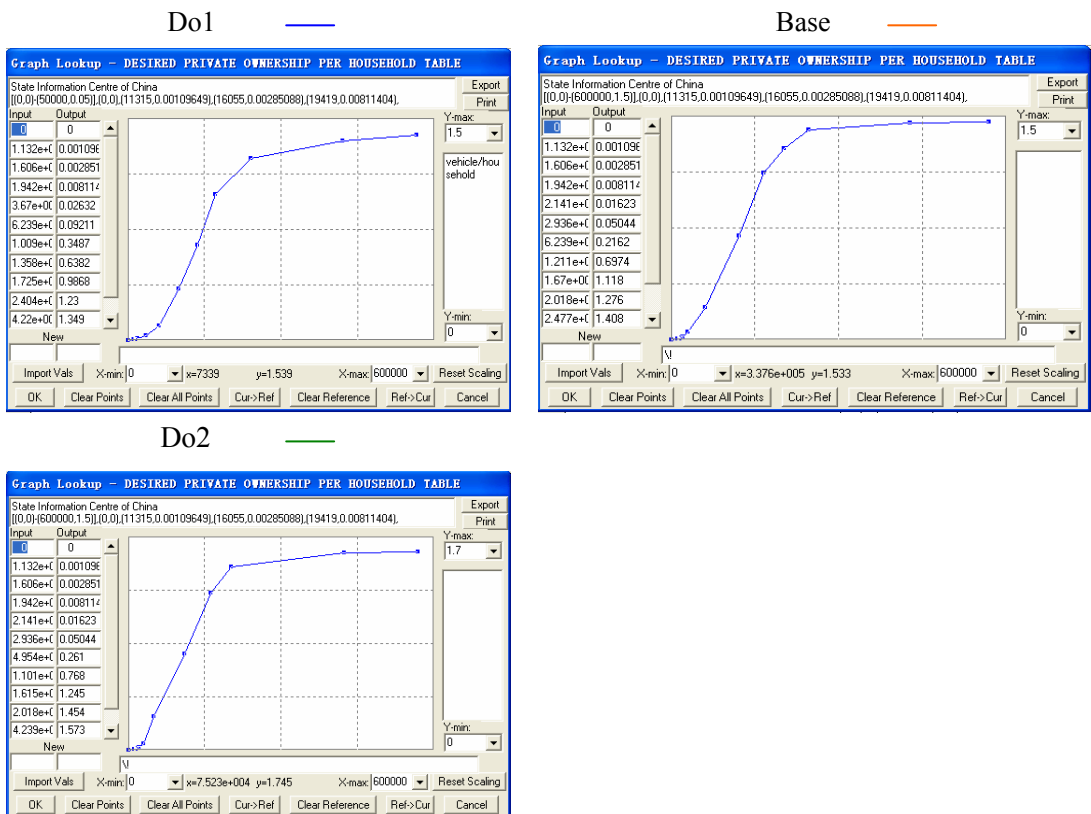
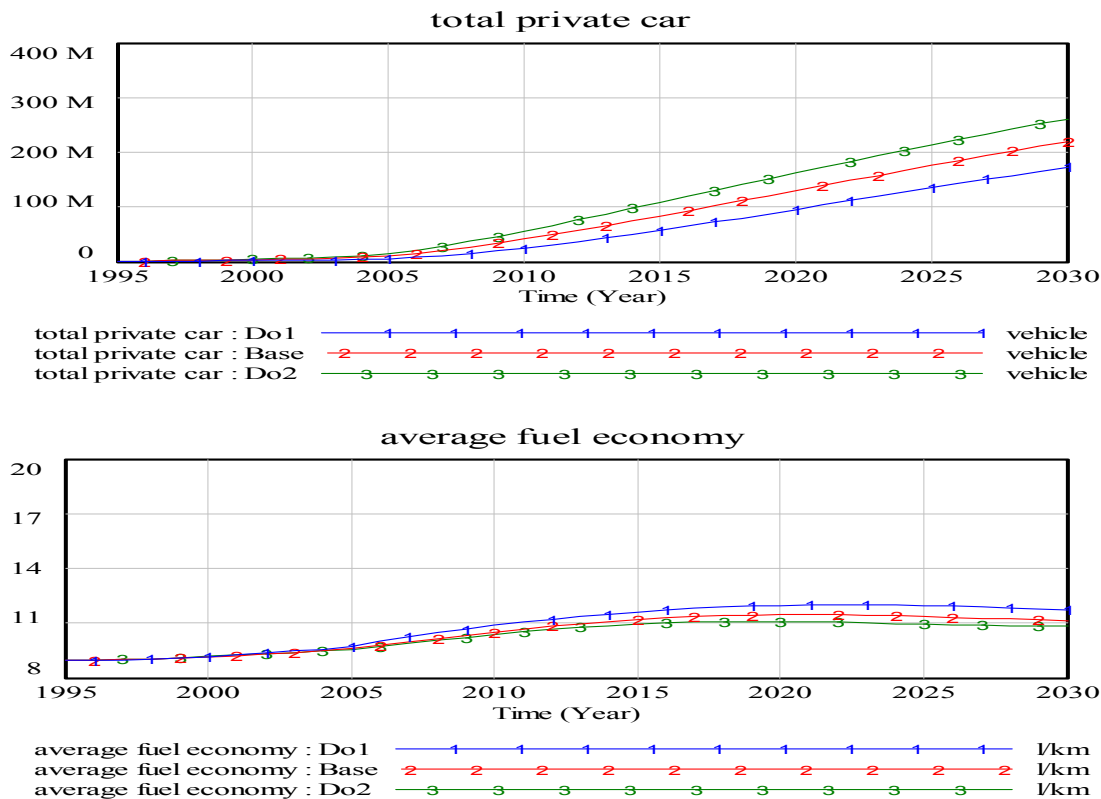


Figure 6-5 Different Desired Ownership Rate



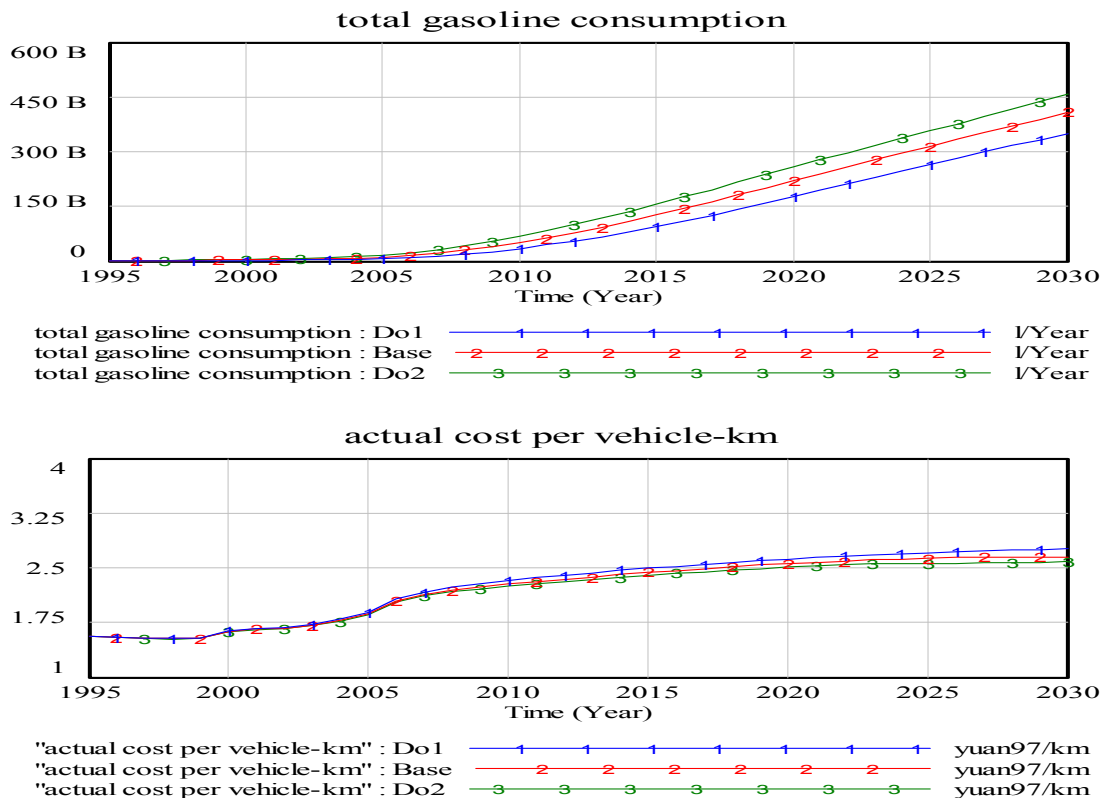


Figure 6-6 Sensitivity Behavior - Different Desired Ownership Rate

Again, no behavioral changes can be observed in this test. The higher desired ownership rate sees the quicker development of total private car ownership and larger consumption of gasoline. Since the average fuel economy considers the fuel economy of both old and new cars on road, the less desired ownership rate causes less inflow of new car purchase, making the improvement of fuel economy on road more slowly than it otherwise would be. Provided other features unchanged, the car with better fuel economy can charge a little bit more than the poor one. As the fuel consumption improvement has been slowed down, the car with certain fuel economy, which is considered poor in the case of higher desired ownership rate, could enjoy the premium for a longer time. This makes the annual insurance and depreciation stay high for a longer time. As a result, the average fuel economy and cost per vehicle kilometer is worst in Do1.

The behavior of this sensitivity test conforms to both the physical reality and known decision rules.

6.7.3 Relative Technology Cost

The relative technology cost represents the relationship of cost and technology improvement for fuel economy. As the technology is reaching its bottleneck, we need more money for the same level of improvement as we did before. Unfortunately, we are unable to get the exact number to figure out the exact curve. We collect some discrete relevant data from professional website, news, expert interview and so on. However, the output of tech investment can be very sensitive to these data. Here we test three different curves as follows to see if it would change the behavior of the model significantly.

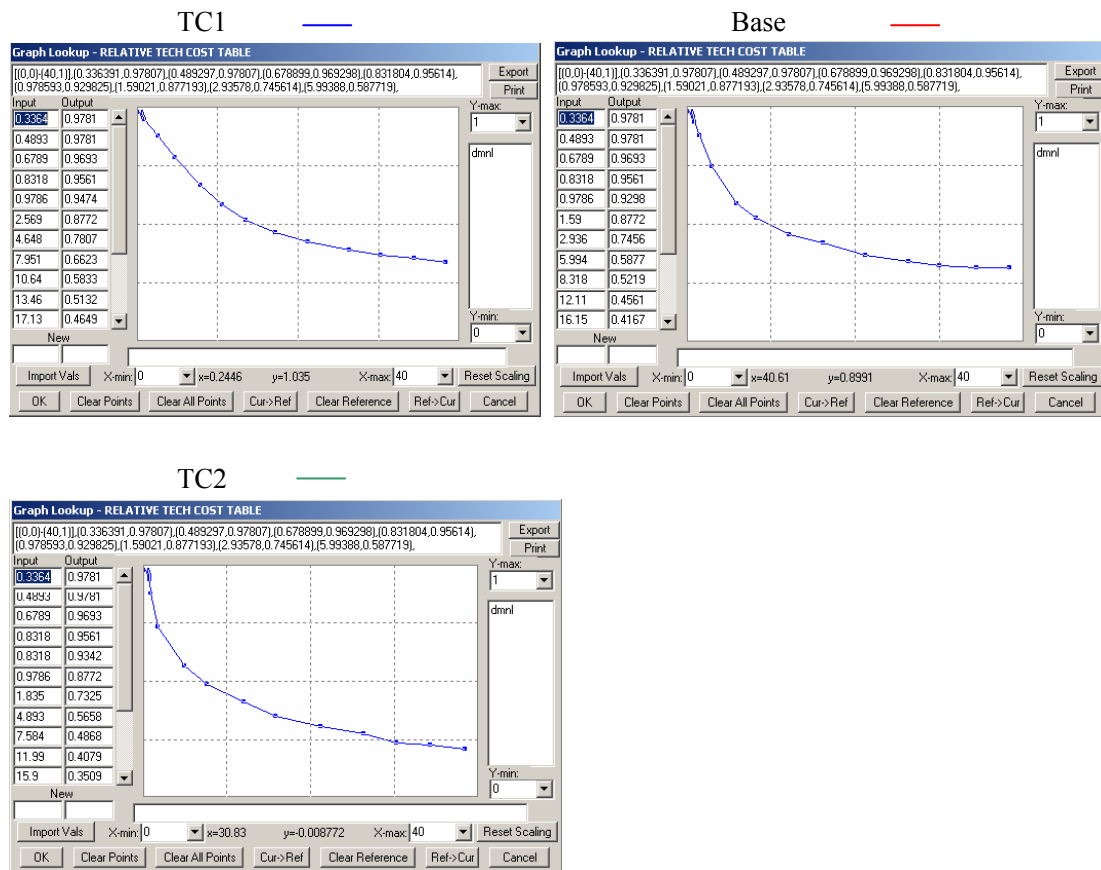


Figure 6-7 Different Relative Technology Cost

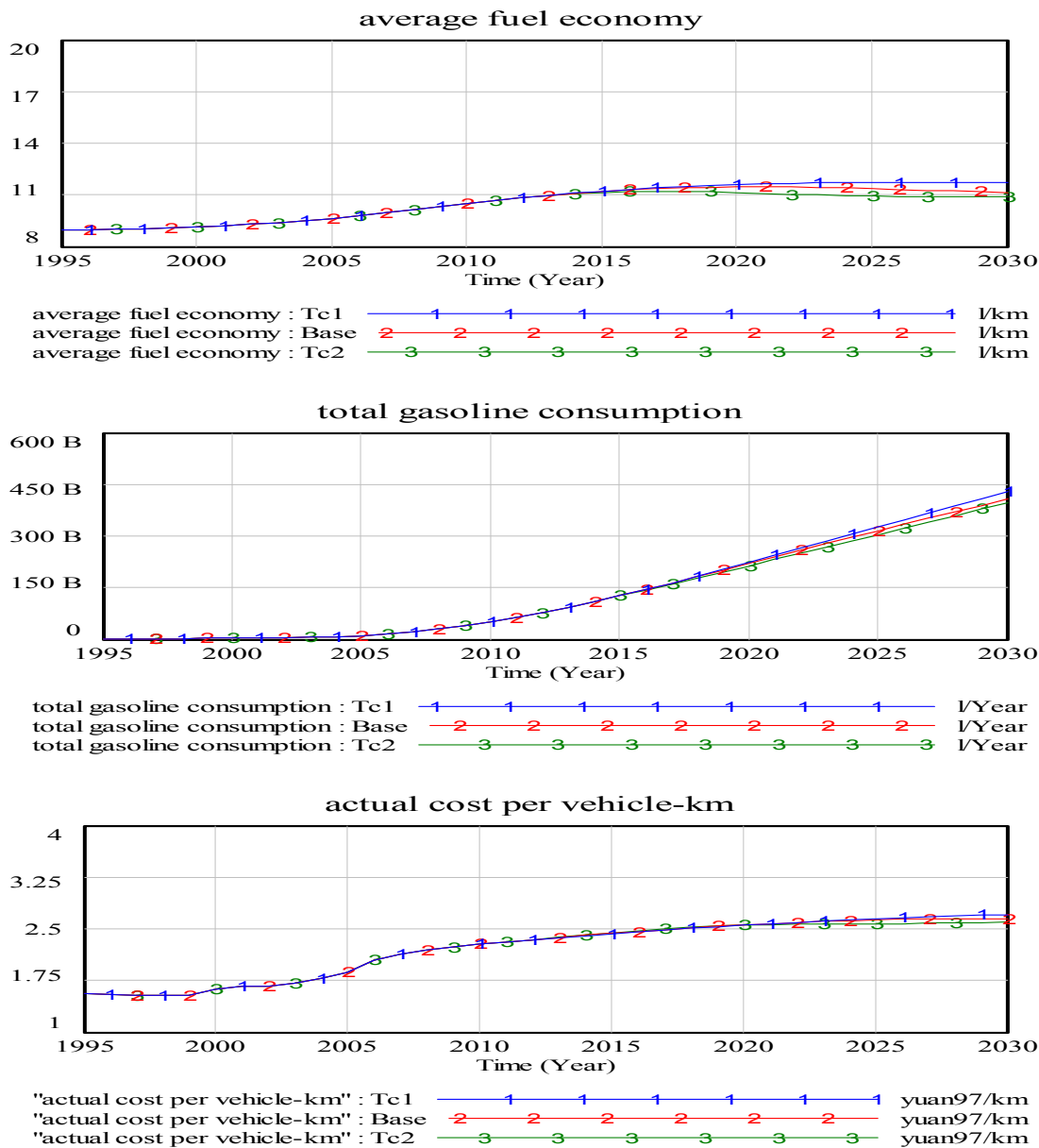


Figure 6-8 Sensitivity Behavior - Different Relative Technology Cost

As what can be seen from the Figure 6-8, the relative technology cost does not significantly change the model behavior. The steepest curve, which means money helps to improve the fuel economy most at the beginning, gets the best result of average fuel economy on road, least total gasoline consumption and least cost per vehicle kilometer.

Chapter 7 Behavior Analysis and Policy Design

7.1 Base Run

In the base run, the value before 2007 are from historical data and after that the gasoline price stays constant from 2007 to the end of the simulation. Additionally, no gasoline tax is imposed on consumers.

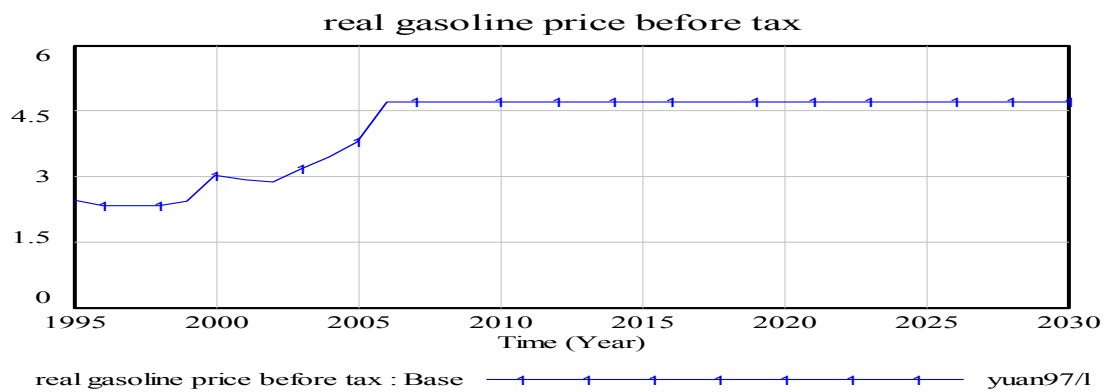
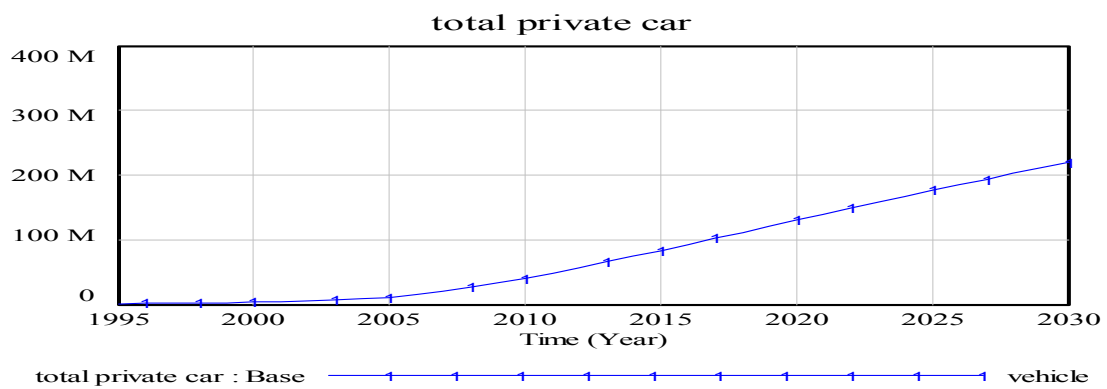


Figure 7-1 Base Run – Gasoline Price before Tax



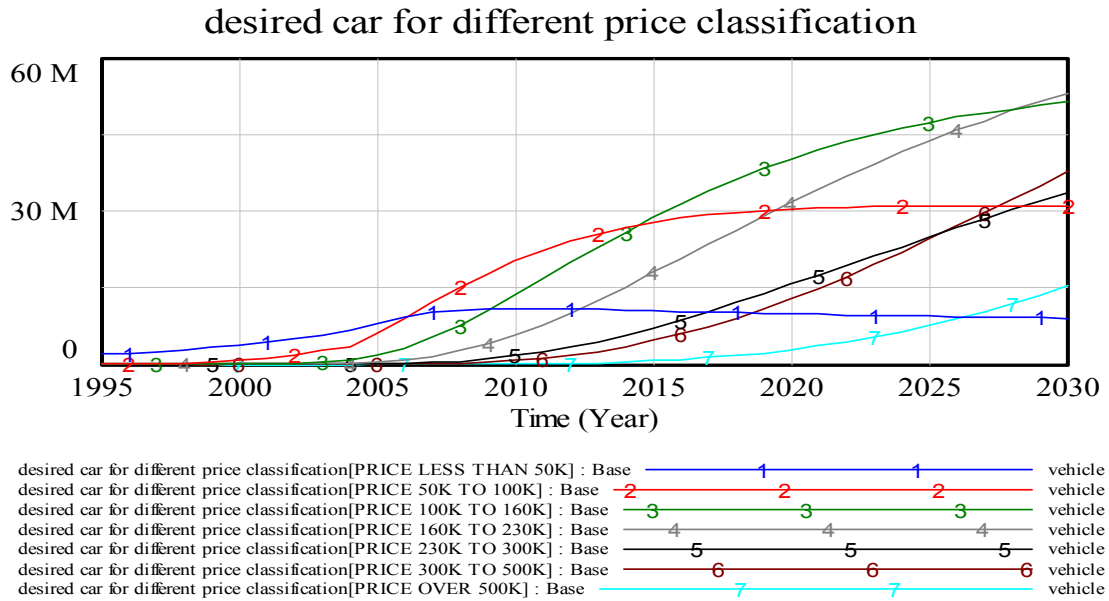


Figure 7-2 Base Run – Private Car Ownership

Due to the rising buying power of Chinese consumers, the private car ownership continues to increase dramatically. The baseline projection for seven car categories is shown in Figure 7-2. As time passes by, the desired private car ownership will concentrate on higher price levels, which normally consist of cars with bigger size and more powerful engine, consuming more gasoline per 100 kilometers. Year 2030 sees the dominance of cars in the price range between 100,000 and 230,000 in the whole market.

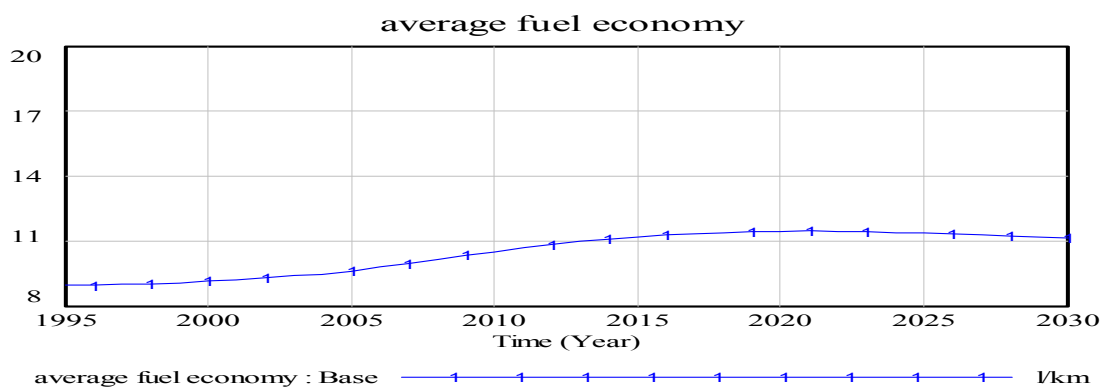


Figure 7-3 Base Run – Average Fuel Economy

Fuel economy is the amount of fuel required to move a vehicle over a given distance. Fuel economy is usually expressed in one of two ways:

- The amount of fuel used per unit distance; for example, liters per 100

kilometers (L/100 km). In this case, the lower the value, the more economic a vehicle is (the less fuel it needs to travel a certain distance);

- The distance traveled per unit volume of fuel used; for example, kilometers per liter (km/L). In this case, the higher the value, the more economic a vehicle is (the more distance it can travel with a certain volume of fuel).

Here in our model, we use the term of liters per 100 kilometers to express the fuel economy, so the lower the value, the more economic a vehicle is. The average fuel economy shows the behavior of overshoot. Even after the gasoline price stays constant from 2007, it does not reach equilibrium immediately. Fuel economy continues to increase at a decreasing rate until it peaks in the year around 2020. Then it begins to decrease and stays at the equilibrium from year 2028.

From the model description in Chapter 5, we know that the average fuel economy on road improves by the inflow of new, better fuel economy cars and the outflow of old, poor fuel economy cars. The fuel efficiency improvement is driven by consumers' preference for better fuel efficient car and automakers willingness to improve fuel economy of new cars, which is influenced by the cost and benefit of fuel-efficient and non fuel-efficient car sales.

Therefore, the behavior shown above in Figure 7-3 results from the increasing purchase of more expensive car, which is relatively bigger and consumes more fuel than smaller car, and the slow improvement of fuel economy.

Some people tend to buy cars with better fuel efficiency for the same price range, but the higher the car price, the lower percentage of people would like to buy economy model of that price range. Since the gasoline price stays constant from 2007, we can expect this percentage decrease. As a result of the dropping market share of 'fuel efficient cars', which consumes less gasoline per 100 kilometers than the average fuel consumption in its category, automakers lower the factional technology investment rate, making the improvement in fuel consumption more slowly. They do not have much incentive, namely profit, to improve fuel efficiency.

Besides, even automakers invest in technology development and adoption unconditionally, it takes some time for the prototype to become car on the product line,

and then on the market, on the road.

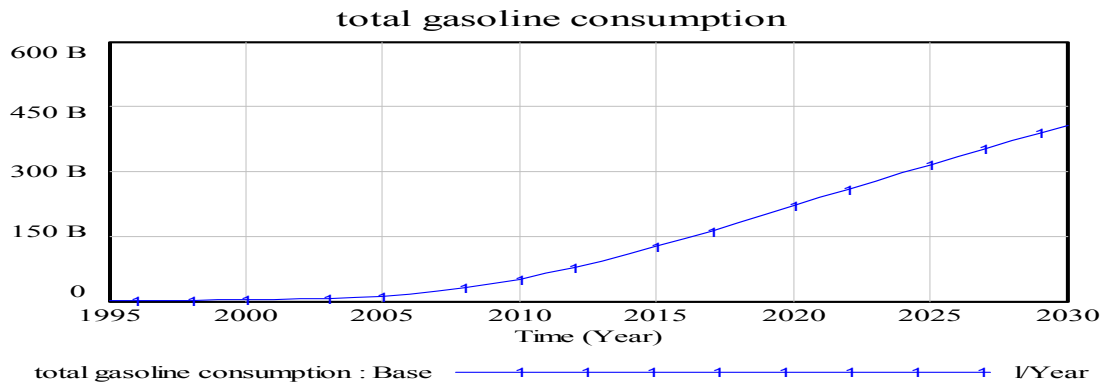


Figure 7-4 Base Run – Total Gasoline Consumption

The total gasoline consumption is determined by average vehicle kilometers per year, fuel economy and total private car ownership. The first two are influenced directly and indirectly by gasoline price with some delay. When the price is higher, we drive less and demand for better fuel economy. The total private car ownership is decided by income level. Since the effect of increasing private car sales on boosting gasoline consumption is stronger than the effect of increasing or stagnant gasoline price on lowering gasoline consumption, the total gasoline consumption continues to grow and shows an exponential growth.

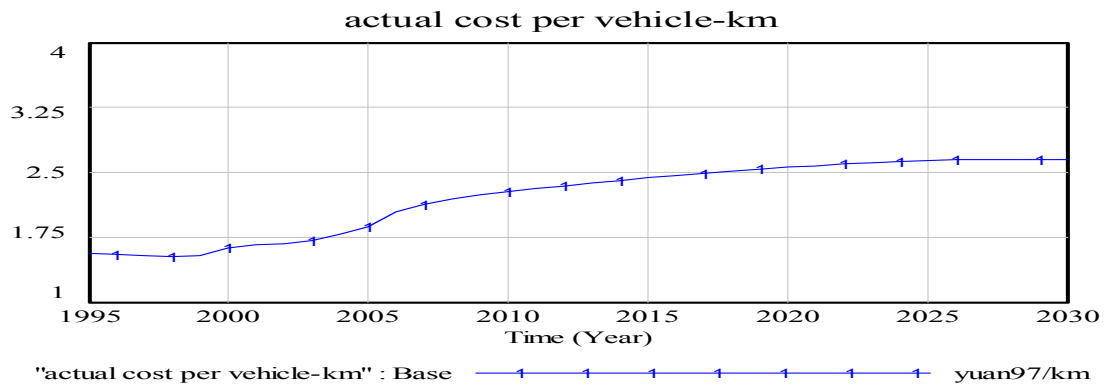


Figure 7-5 Base Run – Cost per Vehicle-km

The total cost includes car insurance, annual depreciation, gasoline expenditure and other operating cost and tax. As fuel economy improves slowly, the gasoline expenditure decrease slowly as well. On one hand, the improvement of fuel economy causes new car price rising. On the other hand, it takes time for the reduction effect of gasoline consumption per car to take place. Consequently, the cost per vehicle

kilometer continues to grow until the reduction effect from technology adoption can offset the increase effect from rising car price.

7.2 Scenario 1: Gasoline Price Stay Constant

7.2.1 Gasoline Tax from 2007 and Remove in 2015

In this scenario, the gasoline price stays constant from year 2007. We would like to see the damage of gasoline tax policy in this situation. The gasoline tax is imposed in year 2007. After seeing gasoline price stay constant for a few years, we remove the tax in 2015. The analysis focuses on the different performance of average fuel economy on road, total gasoline consumption and cost per vehicle kilometer.

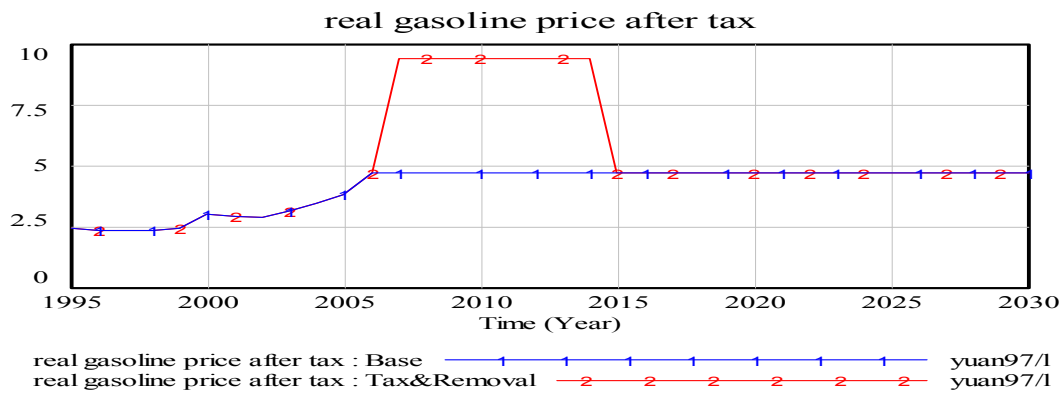
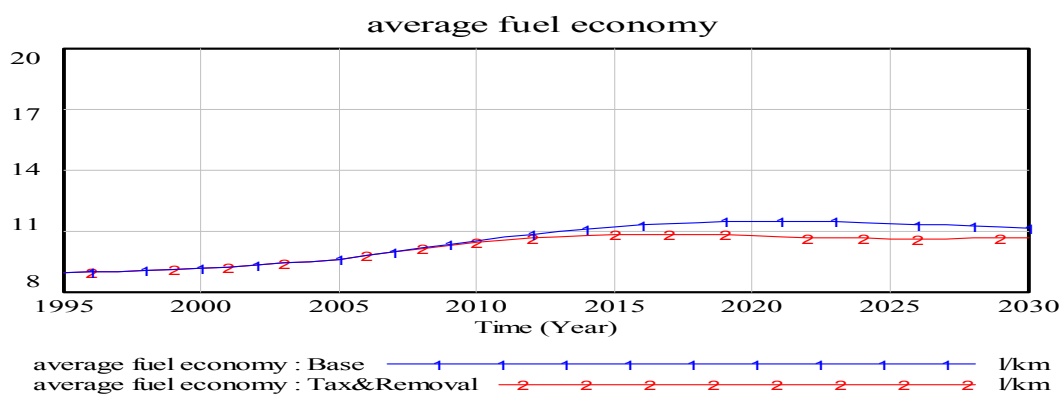


Figure 7-6 Scenario 1 – Gasoline Price after Tax



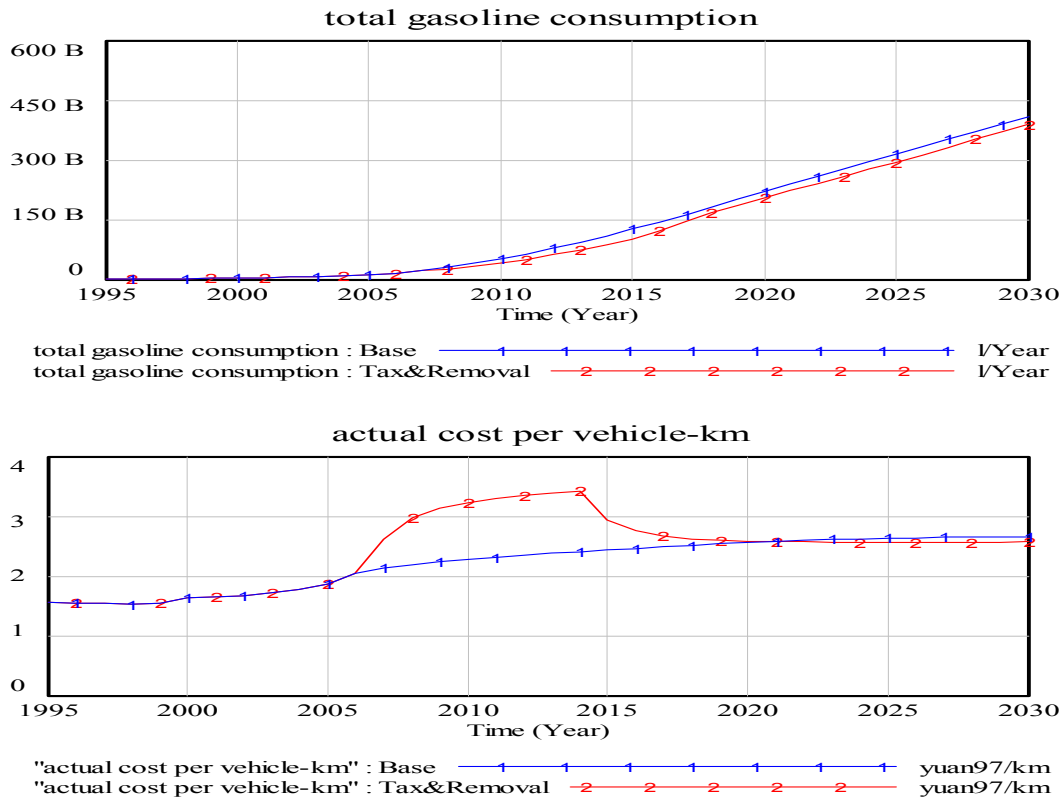


Figure 7-7 Scenario 1 – Tax and Removal Behavior

Compared to the baseline projection, the average fuel economy on road improves a little after the tax imposition. Even the tax is removed in 2015; it stays lower than the base run. Besides, the total gasoline consumption sees a slower increasing rate. Yet, the tax increase the actual cost per vehicle-km from year 2007 to year 2020, and it almost equals the base projection after that.

The tax here slightly improves the average fuel economy and total gasoline consumption but increase the cost per vehicle-km a lot during the tax years.

7.2.2 Tech Subsidy from Gasoline Tax

We try to use all the collected tax as a technology development subsidy for auto manufactures. The same indexes are analyzed.

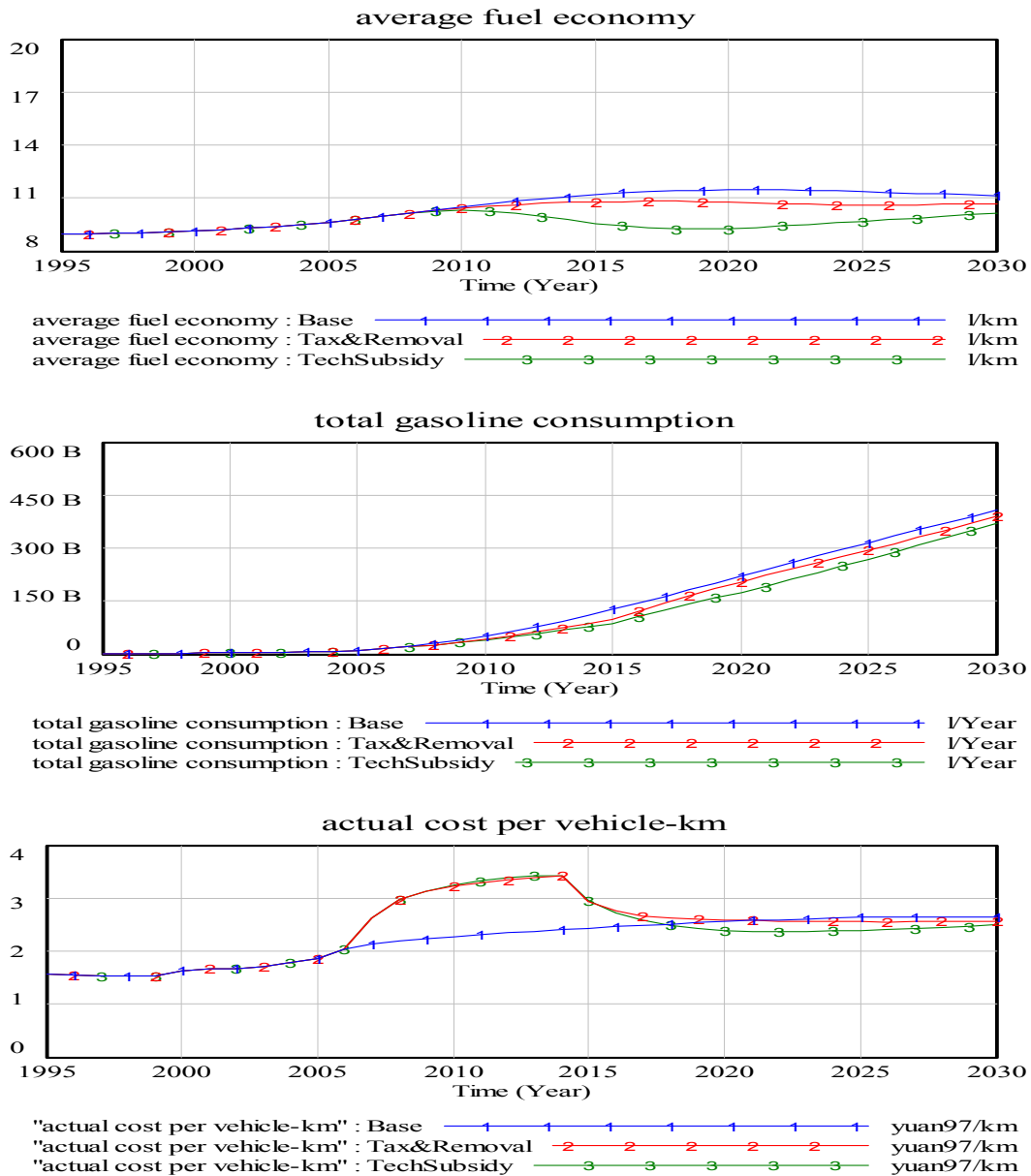


Figure 7-8 Scenario 1 – Tech Subsidy Behavior

The tech subsidy helps to further improve the average fuel economy. Even though the gasoline tax stops in year 2015, the improvement does not stop until year 2020. Though the fuel economy is still much better than in the cases with no tax or tax without subsidy at the end, it begins to increase a bit and reaches its equilibrium after 2020. It is probably due to the fact that auto manufactures sees no further benefit from fuel efficient car sales, so they reduce or stop further technology adoption on product line.

The total gasoline consumption decreases more, compared to the policy of tax 2007. Coming to the cost per v-km, tech subsidy drives the cost less than the no tax

case in 2018, much earlier than the other policy. Additionally, it reaches a lowest cost among the three situations. Yet the cost reduction is far less than the cost increase due to tax imposition.

7.2.3 Tax Refund to Consumers

Assume we can give back the gasoline tax to consumers secretly without affecting the tax impact on average fuel economy and total gasoline consumption.

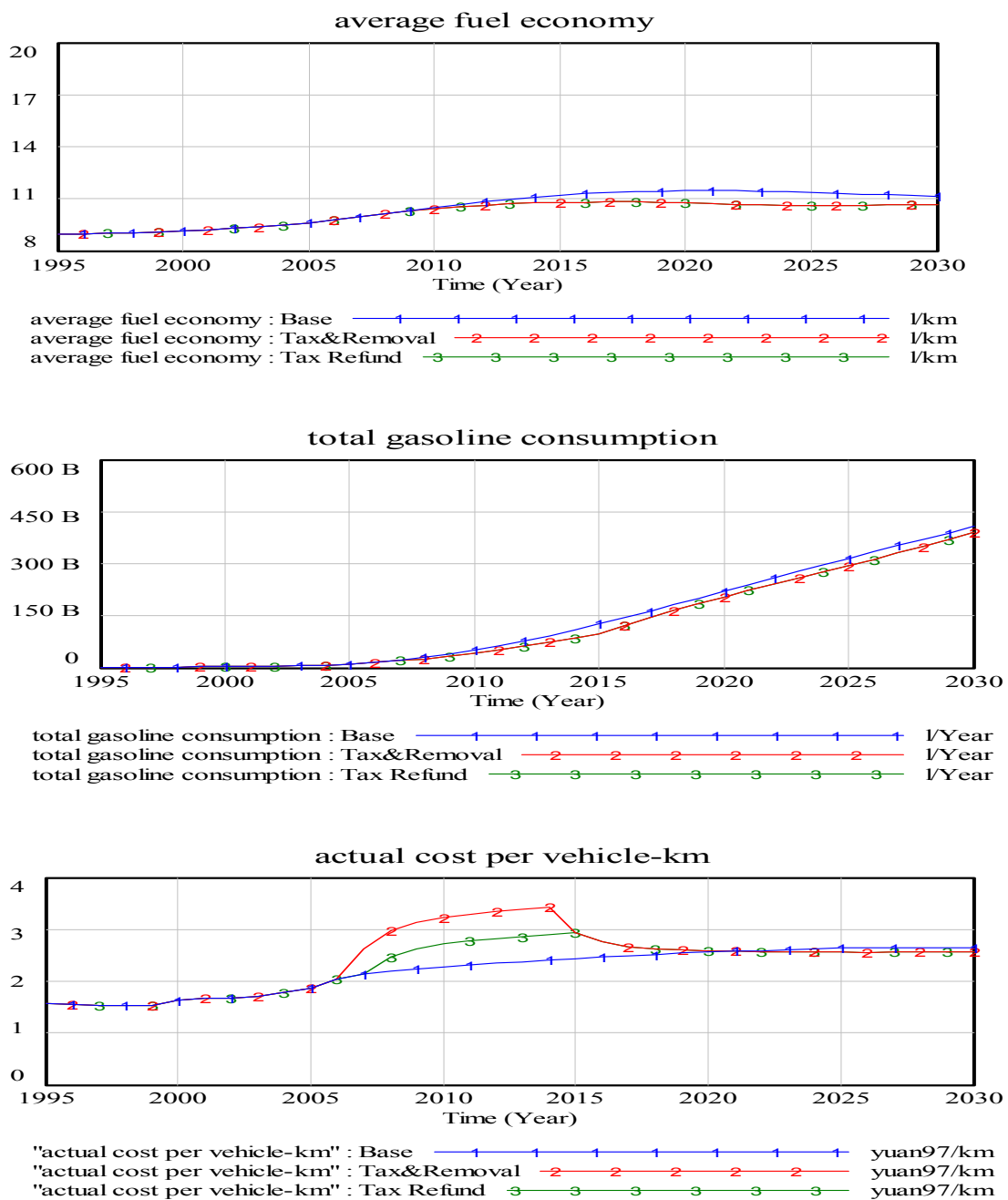


Figure 7-9 Scenario 1 – Tax Refund Behavior

As what we have supposed, the behaviors of fuel economy and gasoline consumption are the same as in the case of no tax refund. However, even we refund the gasoline tax to consumers; it cannot completely make up of the increase cost.

The increasing cost comes from two parts. The first is the rising gasoline price and the second is the rising car price. After the rise of gasoline price, consumers show desire for more fuel efficient cars. In light of strong demand, automakers begin to apply more advanced technology into production and enjoy a markup on car price due to improvement of car fuel efficiency. Considering the rising gasoline expenditure, consumer would like to pay more for the car to get better fuel efficiency.

The tax refund can immediately offset the cost increase from rising gasoline price but not the car price. Car price is determined by the relative fuel economy of new product to the average on the market. Once automakers start production, it is not easy to change their product line overnight. As a result, the price markup from more favorable fuel efficiency would stay until a new product with better fuel efficiency appears on the market.

7.3 Scenario 2: Gasoline Price Step Increase

7.3.1 No Gasoline Tax Application

In scenario two, we assume the gasoline price suddenly double in 2015 and stay constant to the end of the simulation. First, we try to see what happen if we do nothing about it. Then, we apply the gasoline tax to the model to see if we can reduce the loss or change some unfavorable behavior.

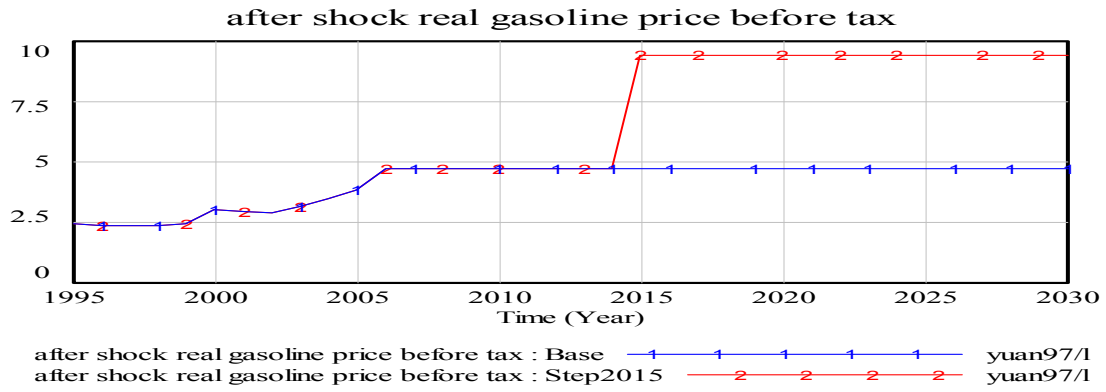


Figure 7-10 Scenario 2 – Gasoline Price before Tax

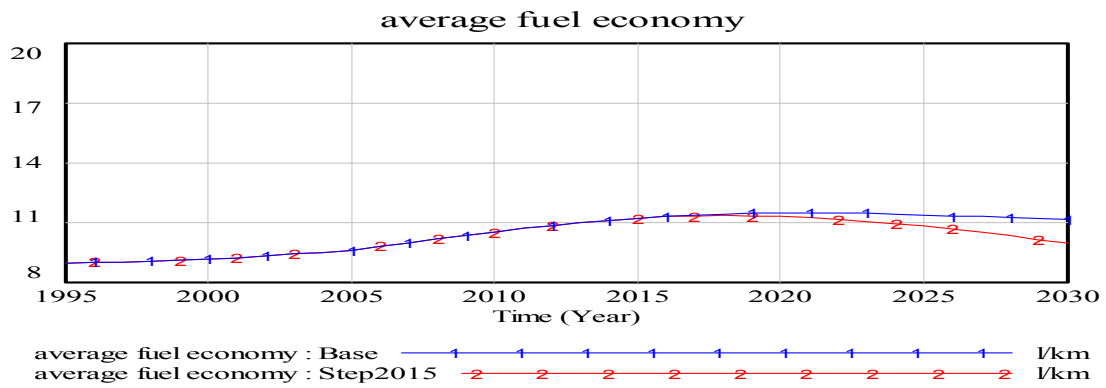


Figure 7-11 Scenario 2 – Average Fuel Economy

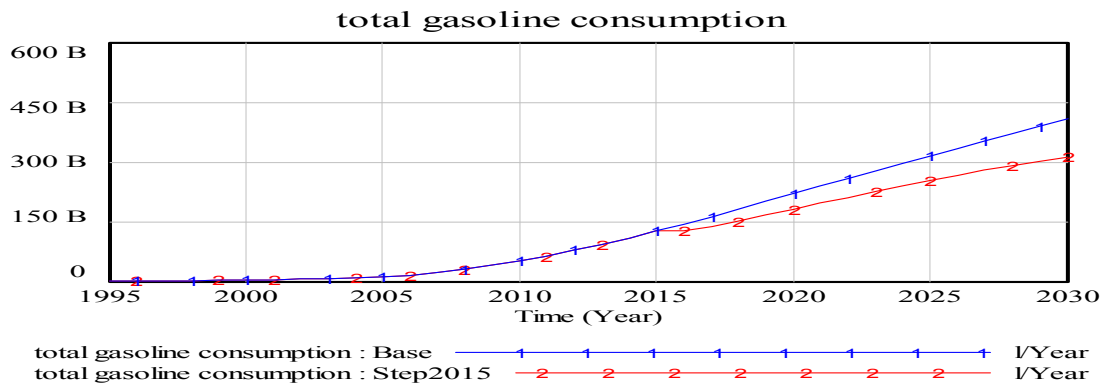


Figure 7-12 Scenario 2 – Total Gasoline Consumption

A few years after the gasoline price double in 2015, consumers’ desire for better fuel efficiency car grows, making automakers to invest more on technology development and adoption. As the fuel economy of new car is much better than before, the average fuel economy on road improves. We see the curve peak lower and drop to a lower equilibrium sooner than in the base run. In the meantime, car owners restrict their driving, namely vehicle kilometers, to some extent, trying to reduce the gasoline expenditure due to the rising gasoline price. Thus, better fuel economy and less

vehicle kilometers, contribute to the decrease of the total gasoline consumption.

So far, the effect of the doubling gasoline price seems favorable; the average fuel economy on road improves and total gasoline consumption decrease. How about the cost?

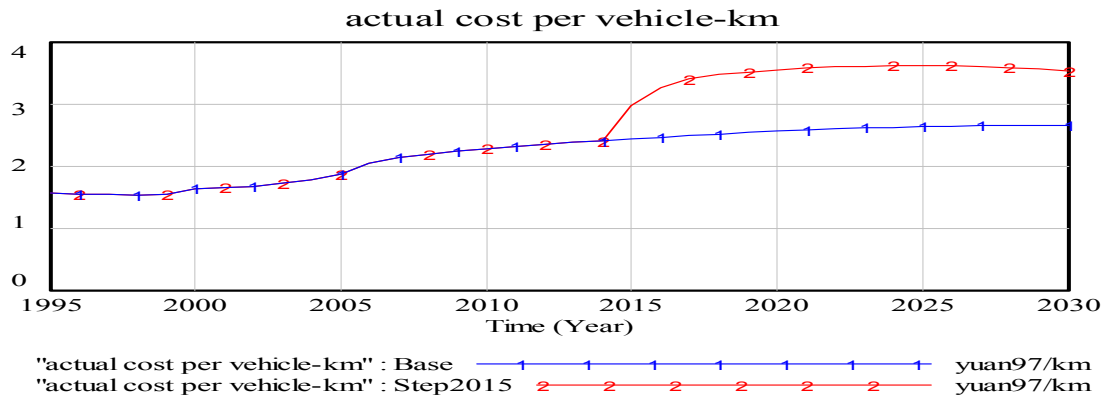


Figure 7-13 Scenario 2 – Cost per Vehicle-km

Even though car owners drive less to reduce gasoline expenditure, new purchase sees preference for better fuel efficiency, and automakers try to improve fuel economy of new cars, they cannot completely neutralize the increase effect for cost per vehicle kilometer. Can we reduce this cost by applying the gasoline tax without adding unfavorable effect to the average fuel economy and total gasoline consumption?

7.3.2 Gasoline Tax from 2014

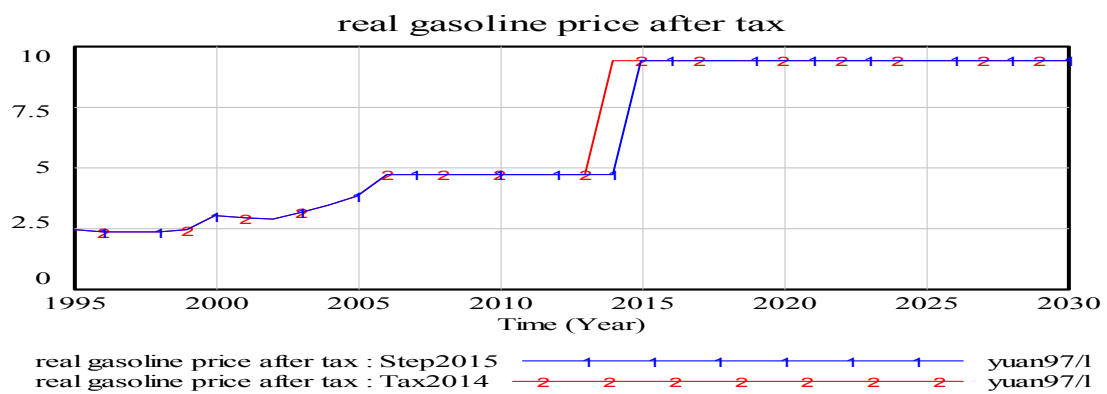


Figure 7-14 Scenario 2 – Gasoline Price after Tax in 2014

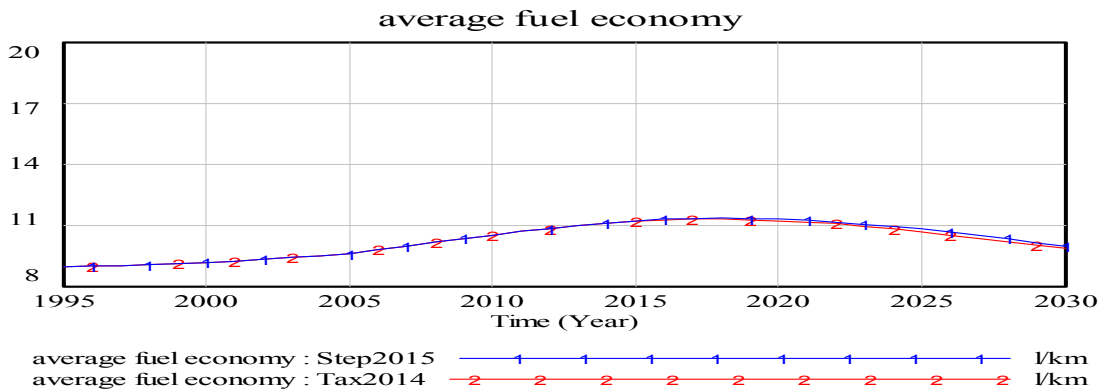


Figure 7-15 Scenario 2 – Tax 2014 – Average Fuel Economy

Here, we are applying a 100% gasoline tax one year in advance and stop the tax when the gasoline price doubles in 2015. From Figure 7-15, we find that one year’s tax has almost no effect on the improvement of the situation. Delay should be taken into consideration and the tax should be applied well before to get some favorable results. Following we would focus on the gasoline tax from 2007 to see its effect.

7.3.3 Gasoline Tax from 2007

Below in Figure 7-16, 100% gasoline tax is applied from the year 2007 and stop when the gasoline price before tax doubles in 2015. It means consumers are bearing the same gasoline price since 2007.

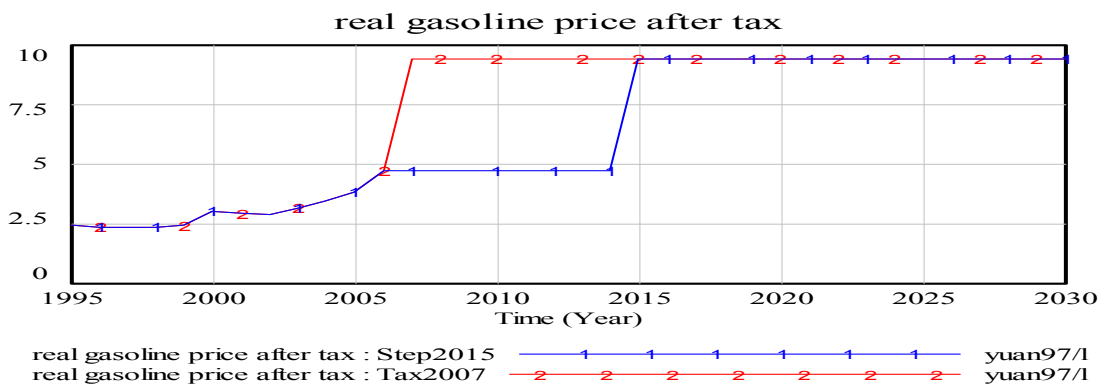


Figure 7-16 Scenario 2 – Tax 2007 – Gasoline Price after Tax

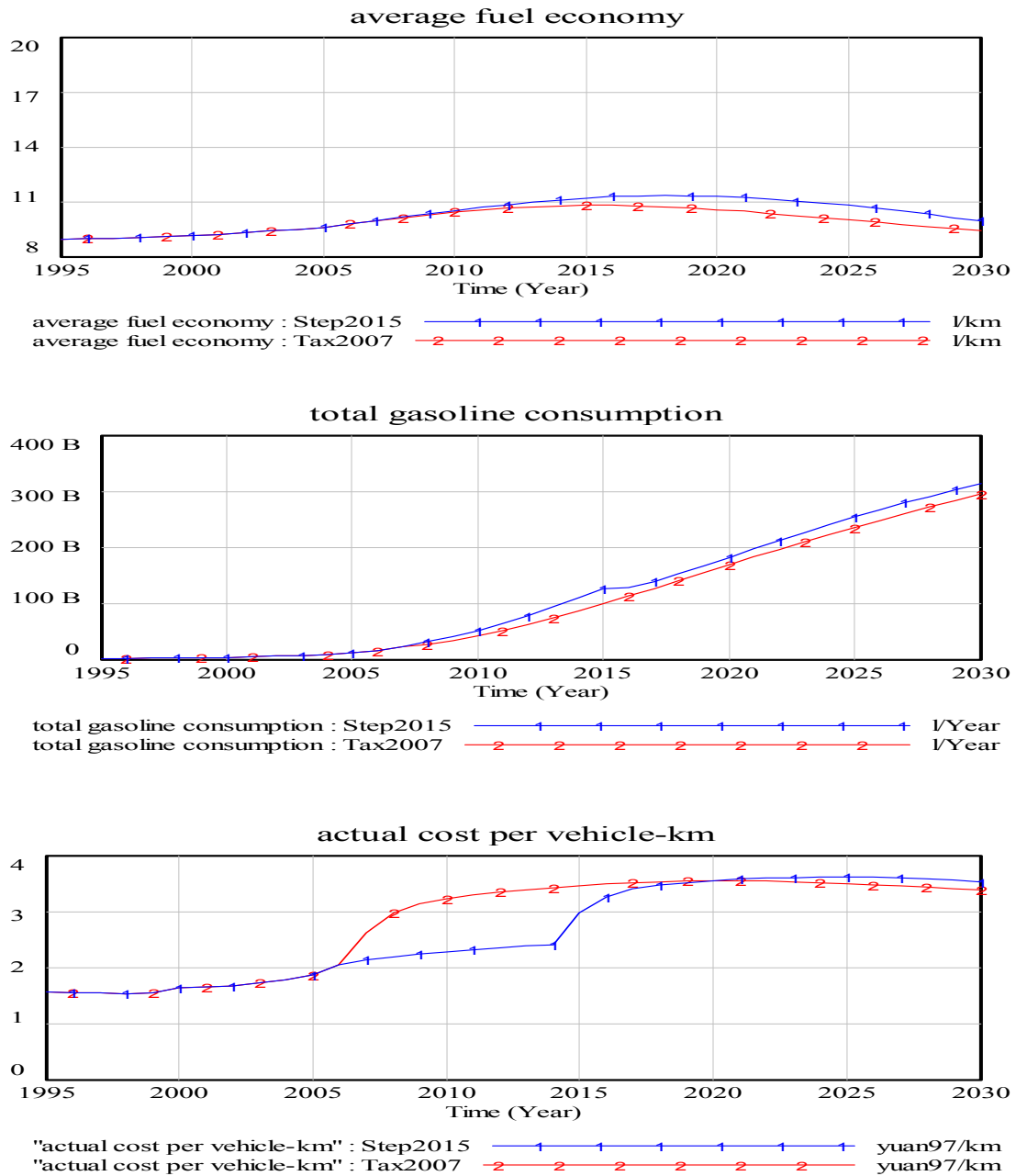


Figure 7-17 Scenario 2 – Tax 2007 – Behavior Comparison

After implementing the gasoline tax in 2007, average fuel economy on road and total gasoline consumption show better performance than in the case without any policy application. The cost per vehicle-km increases from the year 2007 and stays under the curve of step2015 from 2020 to 2030. However, all the effects are not so convincing because the difference is hard to see.

7.3.4 Tax Refund to Consumers

As what we did in scenario 1, here we also apply the tax refund in scenario 2,

without any influence on the tax effect on average fuel economy and total gasoline consumption.

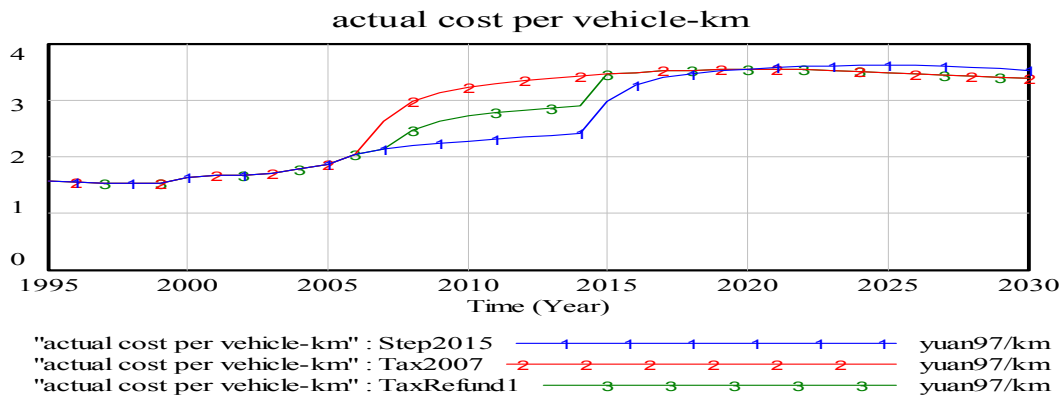
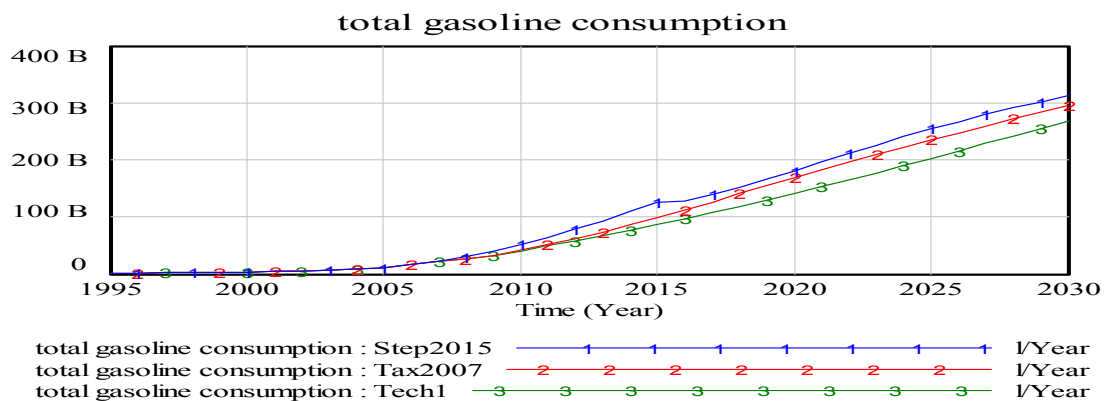
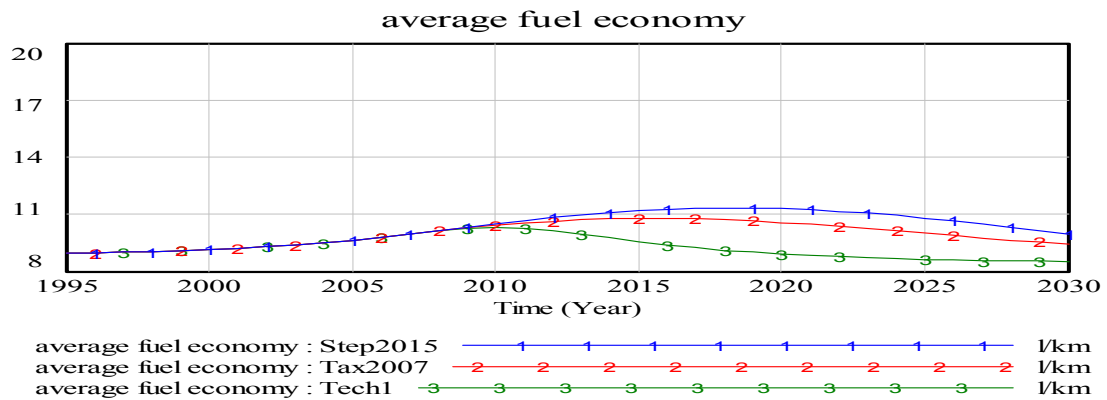


Figure 7-18 Scenario 2 – Tax Refund – Behavior Comparison

The actual cost per vehicle kilometer shows better performance than the previous one in figure 7-18. It reduces almost half the increasing cost. Yet it makes up the cost increase from gasoline tax but not from the car price.

7.3.5 Tech Development Subsidy from Gasoline Tax



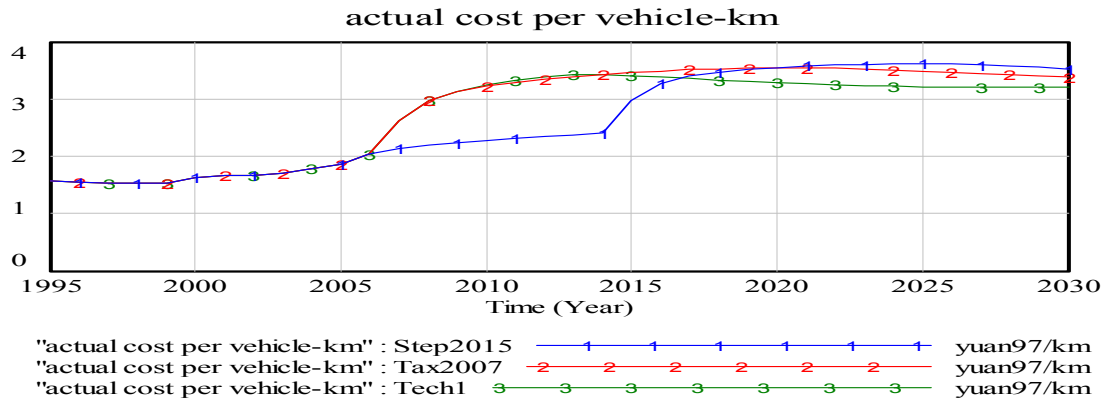


Figure 7-19 Scenario 2 – Tech Subsidy – Behavior Comparison

The figure 7-19 shows the different tracks for three different situations. Step2015 stands for a step increase in gasoline price without any policy. Tax 2007 represents a gasoline tax from the year 2007. Tech1 shows the behavior when we put the collected tax as a subsidy for automakers' technology development.

With the application of tech subsidy, the effect becomes more obvious. For average fuel economy on road, step2015 peaks in the year around 2020, tax 2007 peaks in the year 2015 and tech1 peaks in 2010. Tech1 dips immediately after it reaches its peak and reaches the lowest point among the three, in terms of liters per vehicle kilometer. In contrary, step2015 and tax2007 decrease very slowly to reach a higher equilibrium.

For the total gasoline consumption, the tech subsidy also shows a larger reduction for gasoline consumption than only tax implementation.

Referring to the cost per vehicle kilometer, tech1 begins to be lower than the others from year 2015. It is nearly twice lower than the case in tax2007 and the gap is enlarged through the end of the simulation.

7.4 Scenario 3: Gasoline Price Linear Increase

7.4.1 No Gasoline Tax Application

In scenario three, the gasoline price is assumed to increase linearly from 2007 to 2015, when it doubles its price from 2006. Similarly, no gasoline tax application, gasoline tax from 2007 and technology subsidy are simulated to compare different

average fuel economy on road, total gasoline consumption and cost per vehicle kilometer.

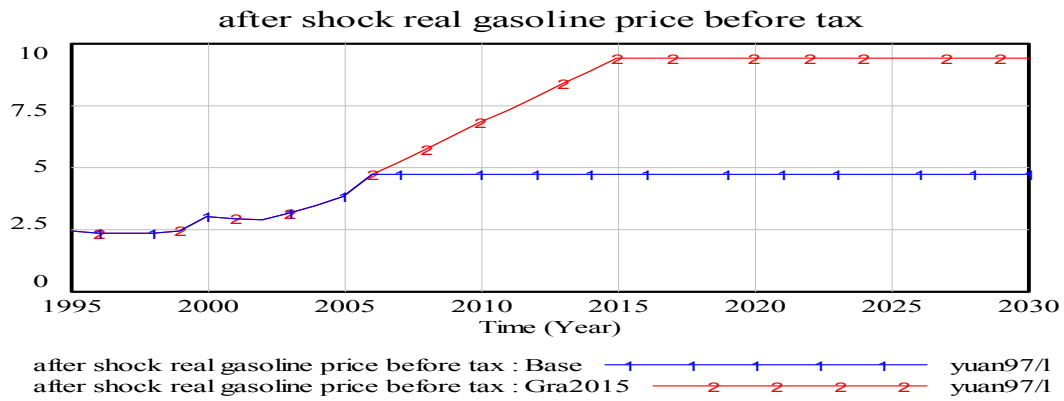
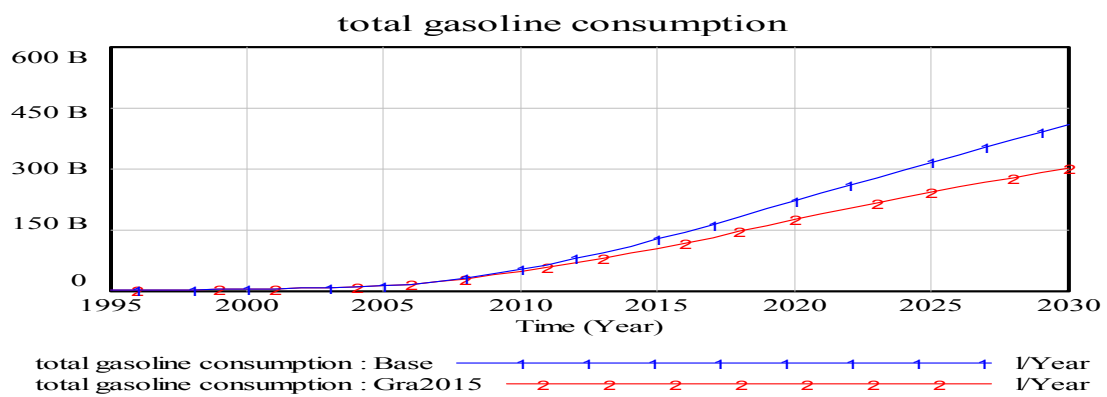
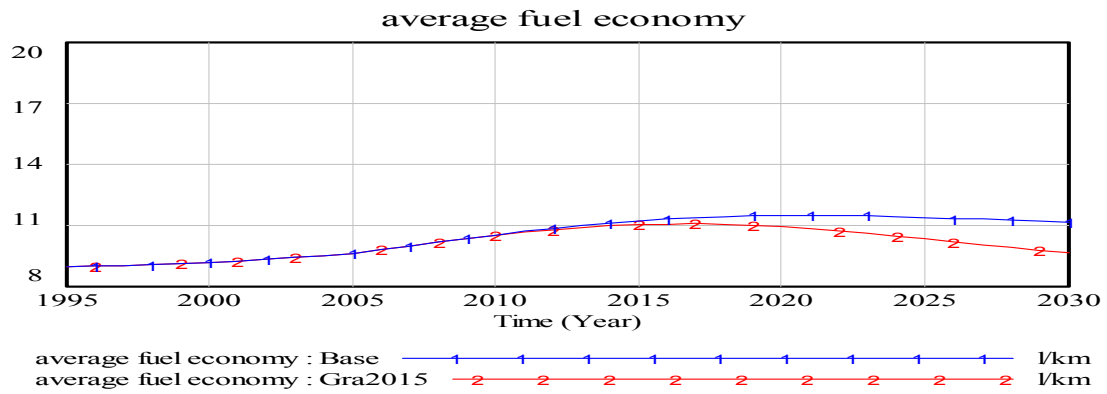


Figure 7-20 Scenario 3 – Gasoline Price before Tax



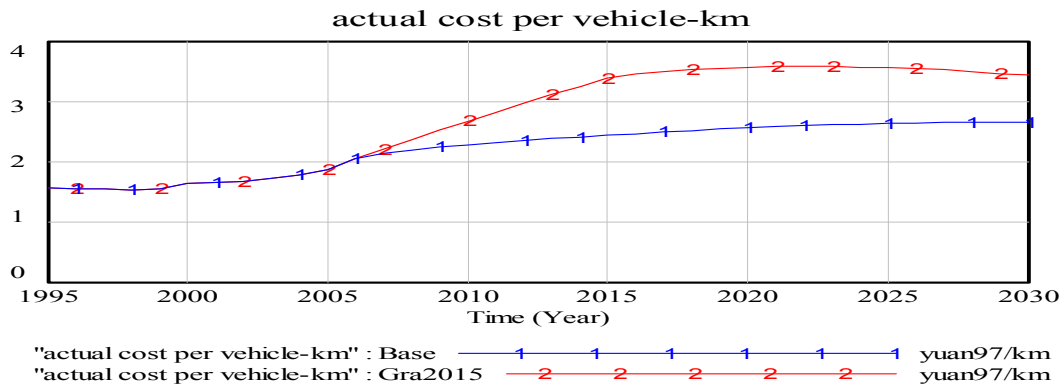


Figure 7-21 Scenario 3 – No Gasoline Tax Behavior

Similar to the behavior in scenario two, we see average fuel economy on road improving after peaking in the year around 2015. Total gasoline consumption increase more slowly than in the base run. Actual cost per vehicle kilometer is higher than that in the base run. Following, we are trying to explore the potential solution to reduce cost while remaining the benefit from average fuel economy improvement and more slowly increased total gasoline consumption.

7.4.2 Gasoline Tax from 2007

Below in Figure 7-22, gasoline tax is implemented from the year 2007. The tax rate is adjusted to keep the gasoline price after tax twice as much as what it is in 2006. When the price before tax doubles in 2015, all the taxes are removed. So, for consumers, the price they have to pay is always twice as that in 2006 from 2007.

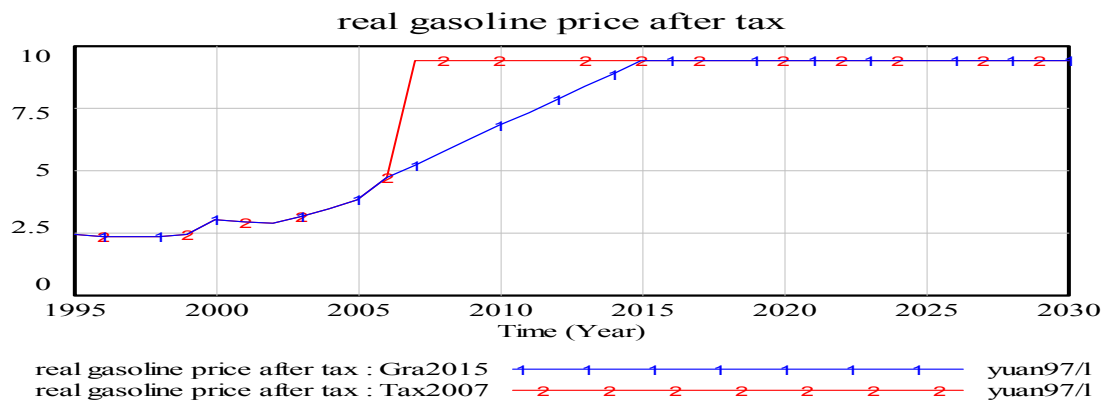


Figure 7-22 Scenario 3 – Tax 2007 – Gasoline Price after Tax

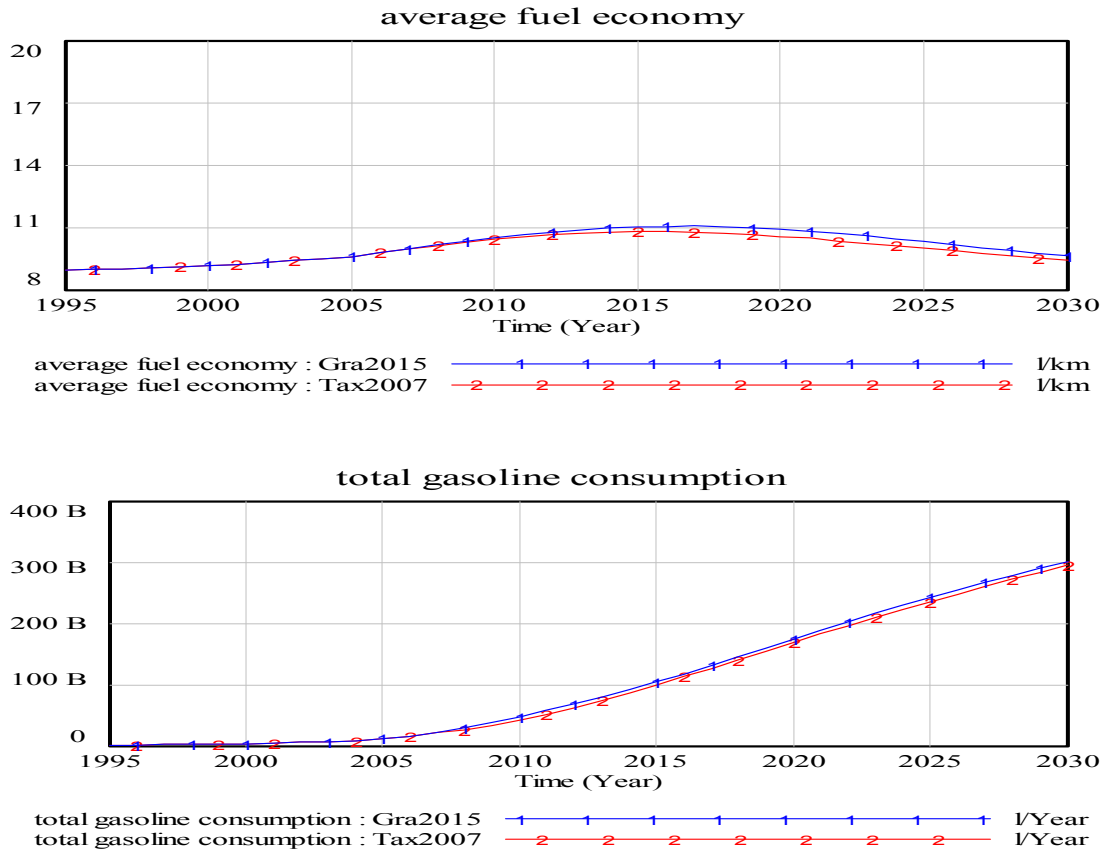
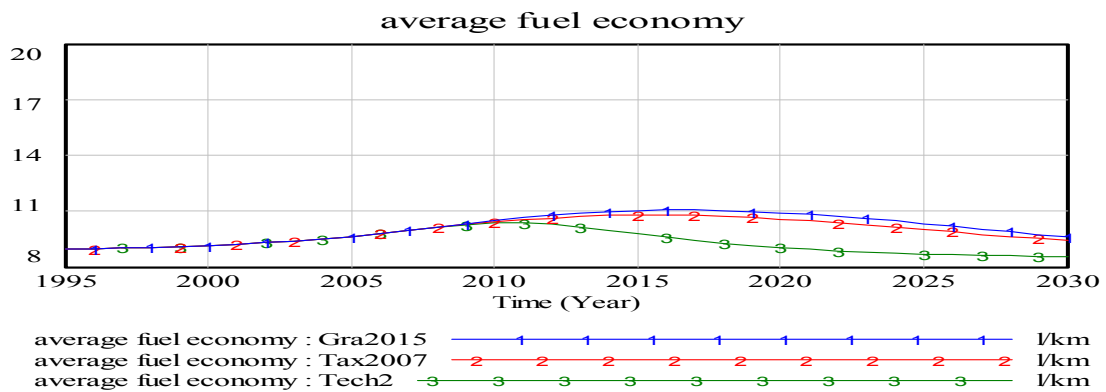


Figure 7-23 Scenario 3 – Tax 2007 – Behavior Comparison

Unfortunately, in this comparison, we cannot see any obvious improvement after the tax implementation in 2007. Average fuel economy on road stays nearly the same, and so does the total gasoline consumption.

7.4.3 Tech Development Subsidy from Gasoline Tax



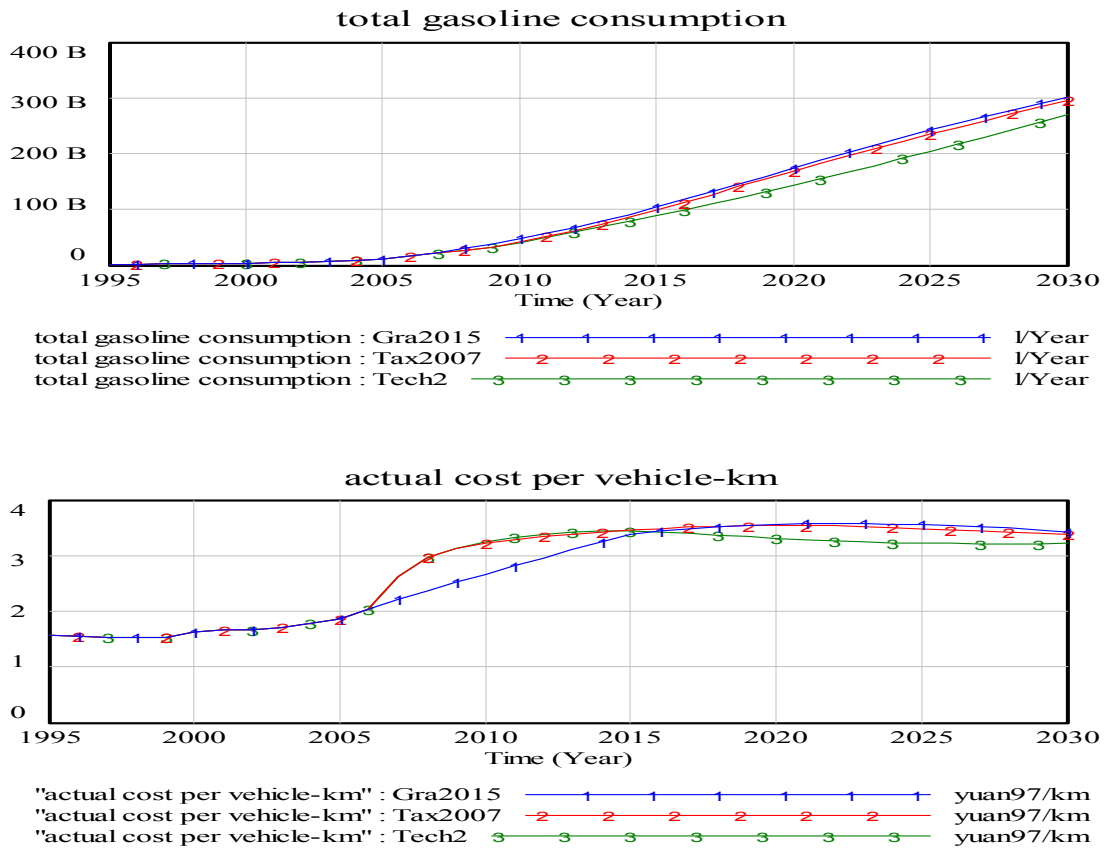


Figure 7-24 Scenario 3 – Tech Subsidy – Behavior Comparison

Still, we can see the favorable contribution from technology subsidy. The average fuel economy on road reaches its peak around 2010, which is much earlier than in the other two cases. It begins to drop dramatically thereafter and reaches a lower equilibrium point in year 2025. The total gasoline consumption increases more slowly and the cost per vehicle kilometer keeps lower than it is in other cases from the year 2015.

7.5 Implication

In the scenario when gasoline price stays constant since year 2007, we can clearly identify the impact of gasoline tax on cost per vehicle kilometer. Even though we refund all the tax collection to consumers, we can only offset the cost increase from gasoline price but not that from car price. The average fuel economy on road and total gasoline consumption shows better performance after tax imposition though.

The behavior analysis and policy design above implies the effect of gasoline tax

if the gasoline price before tax in 2015 reaches twice as much as it is in 2006. In the step increase scenario, the earlier gasoline tax implementation proves a better and more obvious effect. Taking the collected tax as technology development subsidy to automakers yields the most favorable result among the three situations – no tax, tax from 2007 and tech subsidy.

In the linear increase scenario, tax from 2007 is unable to get an effect as good as before. However, the technology development subsidy keeps a good record. It improves the average fuel economy on road, slows down the increase of total gasoline consumption and reduces the cost per vehicle kilometer.

Chapter 8 Conclusion

8.1 Major Findings and Results

8.1.1 Understanding of the System

From the base run, we can understand some basic dynamics of the system.

Ubiquitous delay

Delays are pervasive. It takes time to measure and report information. It takes time to make decisions. And it takes time for decisions to affect the state of a system. A delay is a process in which output lags behind its input in some fashion. Delays are a critical source of dynamics in nearly all systems.

In contrary to what people might think, the average fuel economy on road does not stay unchanged immediately after the gasoline price becomes constantly flat. Instead, it continually gets worse before going down back to a better equilibrium point. People need time to adjust their expectation of gasoline price, their preference for car purchase and their driven distance. Also, it takes time for automakers to collect information about consumer behavior, and alter investment in technology development and adoption. Last but not the least, car with new fuel economy cannot replace the old ones overnight and it would stay on the road for a long time before it is scrapped. In summary, what we do today takes time to get the result.

Inconsistent event-based decision making

Besides, faced with the overwhelming complexity of the real world, time pressure, and limited cognitive capabilities, we are forced to fall back on rote procedures, habits, rules of thumb, and simple mental models to make decisions. In the process of modeling, we refer to some literatures, surveys and make some informal interviews to decide the decision rule of consumers and automakers. We find that people usually make decisions based on simple events.

Consumers make their purchase decisions simply by investigating costs for different cars. Automakers make investment and substitution by calculating costs and

benefits on hand. The mental models people use to guide their decisions are dynamically deficient. They generally adopt an event-based, open-loop view of causality, ignore feedback processes. Hence the decisions they made are not consistent all through the time and normally short sighted, which is contrary to perfectly rational.

8.1.2 Hints for Policy Making

We hope to see from the model how much impact the government can have on leading the private economy toward energy conservation rather than ultimate visions of energy consumption markedly reduced from the one now in place. A better understanding of the dynamics of gasoline tax may be a good beginning to enlighten the government on this issue.

Better early than late

We assume a double gasoline price of year 2006 in year 2015. In the case of step increase, the improvement of average fuel economy on road and reduction of total gasoline consumption increase rate is more obvious if we implement gasoline tax earlier. The resulting effect from late action is almost the same as the case when no action is taken. In the case of linear increase, even the earlier action can only see slight improvement from the no action case. Needless to say how it works if we apply the policy much later than that. In light of what we understand from the model, we really should do the right things before it is too late.

Worse before better

Inevitably, consumer's cost per vehicle kilometer is climbing after the implementation of gasoline tax. That's the ground those against the gasoline tax stand on. Most of us agree that the gasoline price is highly likely to continue increasing in the future. From this point of view, it is reasonable for us to presume the increase in year 2015. We cannot argue the cost will be lower than it otherwise would be from the starting of gasoline tax collection. However, we surely see after the increase of gasoline price, we enjoy a lower cost per vehicle kilometer mainly due to the improvement of fuel economy. Our spending is better off after a slight increase in the

first few years. At the end, we not only see the technology improvement, total gasoline consumption reduction, but also cost reduction. As a policy maker aiming at long-term social effect, we should learn to stand the worse result for a short time and be glad to see better after worse.

Neutralized tax

We tested the policy of putting collected tax into technology development as a subsidy. This policy is revenue-neutral, meaning that the amount of money collected through tax equals the amount paid out in subsidy. In all price increase scenarios, tech subsidy receives more obvious and more favorable effects amid the three.

Fuel tax creates important price signals that can make consumers aware of the non-internalized costs of fuel consumption and remind buyers to take into account the additional cost such as high gasoline taxes or poor gasoline vehicle-km when purchasing a car. Also, fuel tax raises funds to promote greater fuel efficiency, increasing the profitability of new car.

However, if the gasoline price does not rise at all, the gasoline tax could make some damage to car owners. The tax or tech subsidy can reach a lower cost at the end, but tax refund to consumers is probably not enough to cover the cost increase due to tax imposition. The tax can not only increase the gasoline price but also the new car price. Even the gasoline price is highly unlikely to stay constant; we should keep this special situation in mind when making policies.

8.2 Limitations and Future Work

This research is limited in nature by the boundary chosen. The total gasoline consumption is determined by the vehicle ownership, vehicle kilometer driven and fuel economy. The energy conservation impact from kilometer traveled is limited by the exclusion of public transportation in the current model.

Besides, we only consider the first-time buyer for private vehicles, neglecting trade in cycle and the used car market so far. As the economy strengthened along the time, trade in and used car market may play a more and more important role in

China's vehicle market.

Even car purchase is mainly determined by the disposable income and vehicle selling prices, but these are not the only ones. Vehicle operating costs, availability of financing, terms of financing, interest rates, and various fees and taxes are having a bigger effect on people's purchase behavior. Those factors may be taken into account to more precisely reflect the development of China's vehicle market.

The aggregation is high in this study. Automakers are considered as a whole party and the competition in the auto industry is not addressed by the model. Diesel powered private passenger vehicles are not distinguished from gasoline driven vehicles.

Along with extension to bus, taxi and institutional vehicle market for the model structure, more policies besides gasoline tax can be tested and externalized cost such as CO₂ emission may be considered.

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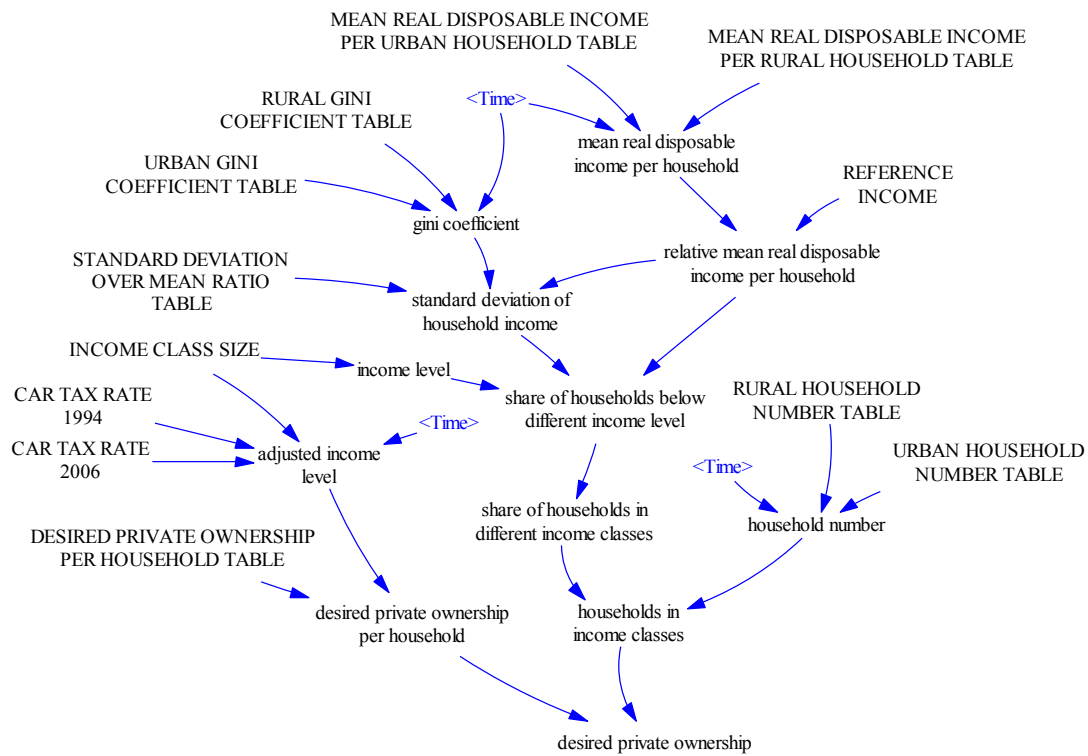
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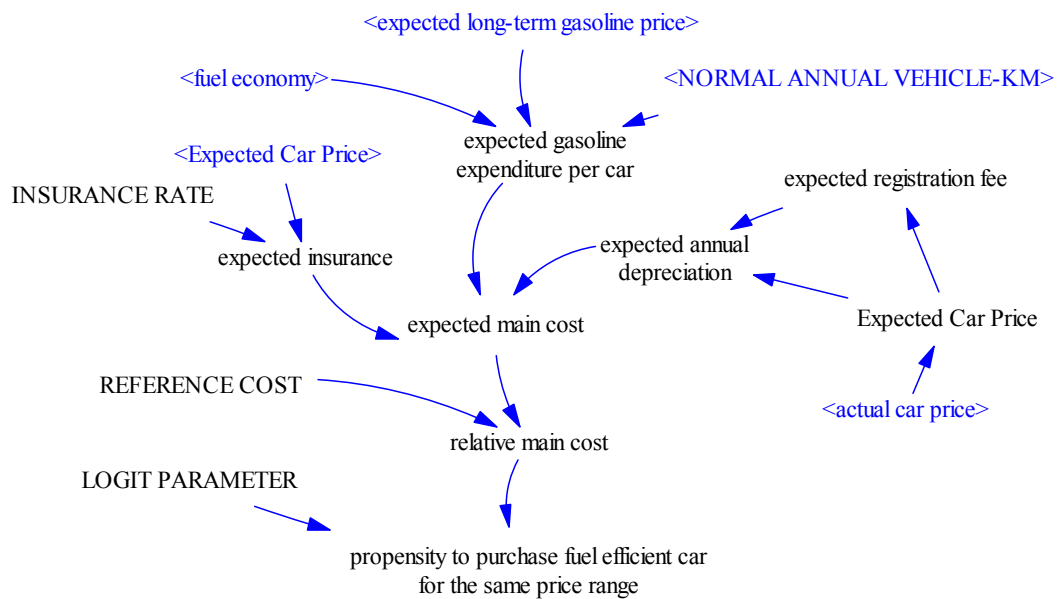
Appendixes

Appendix 1 Model Structure

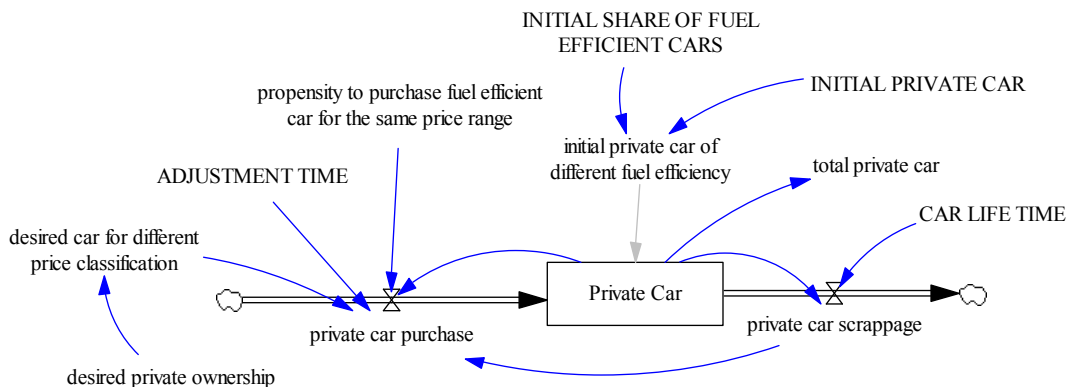
1.1 Desired Private ownership



1.2 Propensity to Purchase Fuel Efficient Car for the same price range



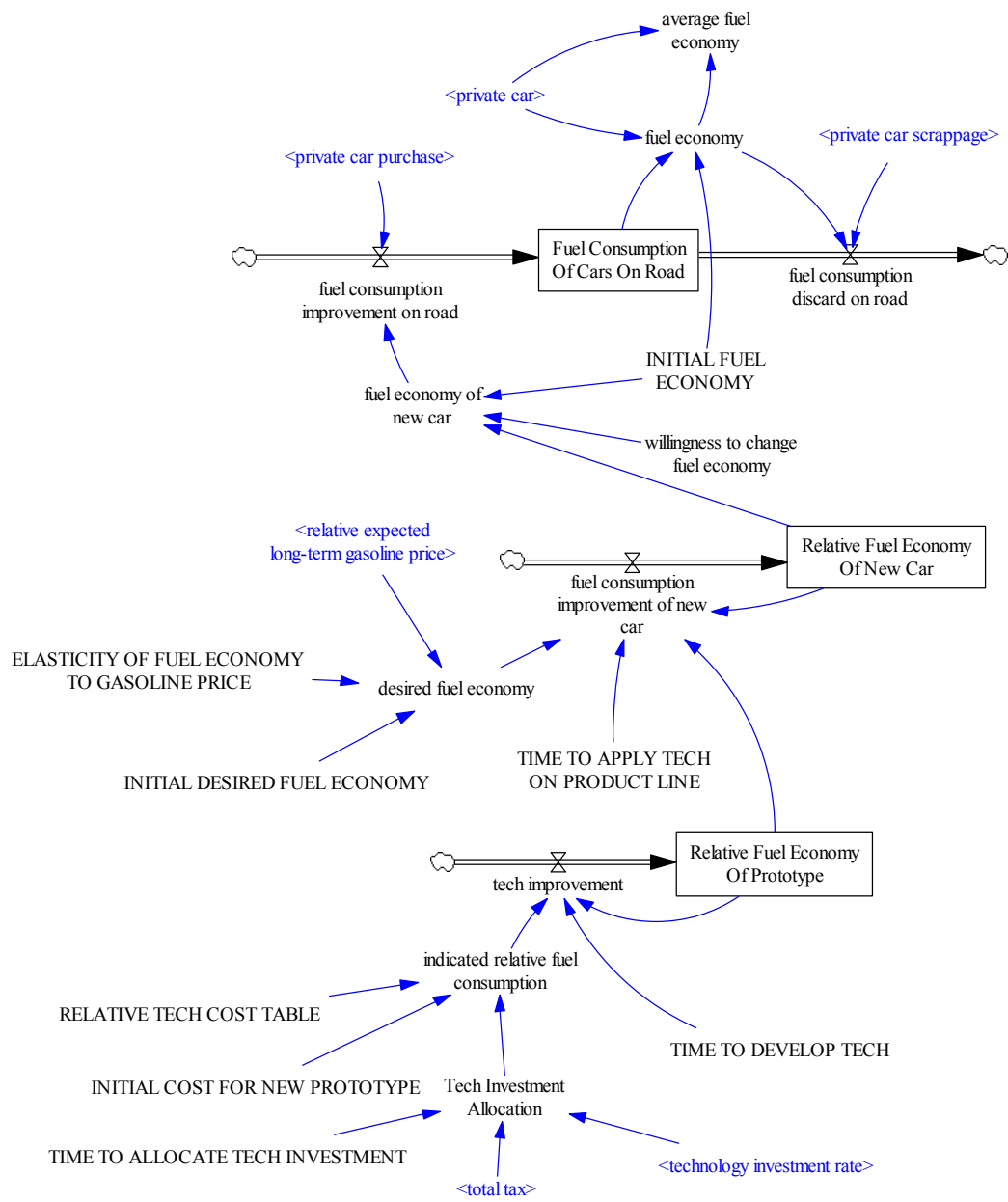
1.3 Private Car Ownership



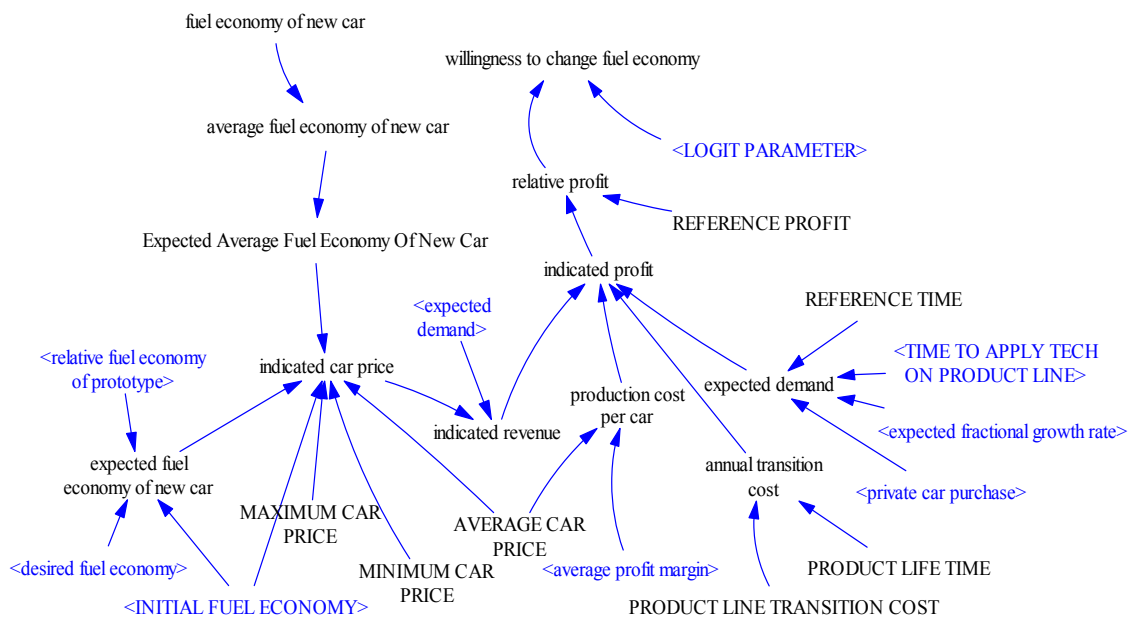
1.4 Technology Investment Rate



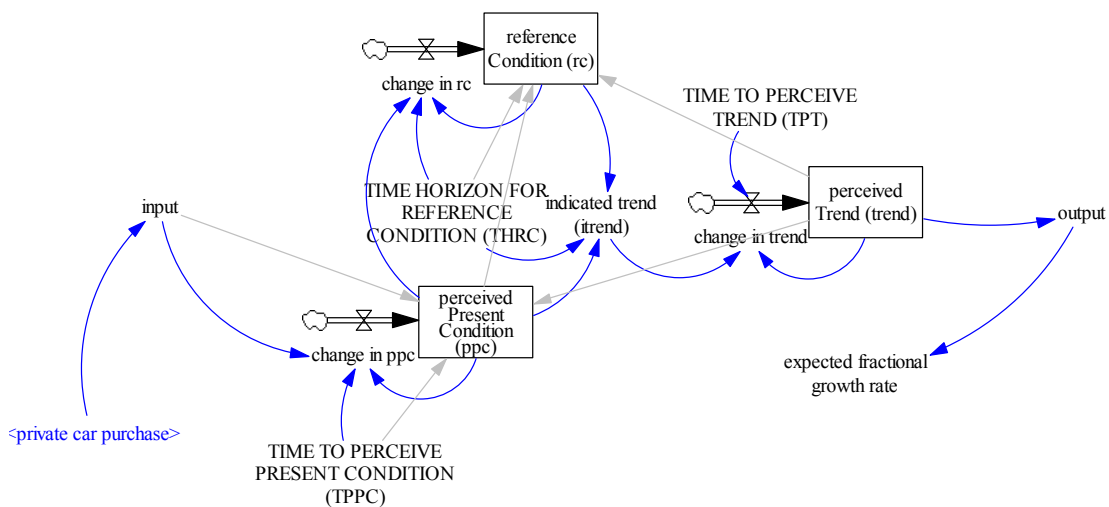
1.5 Fuel Economy



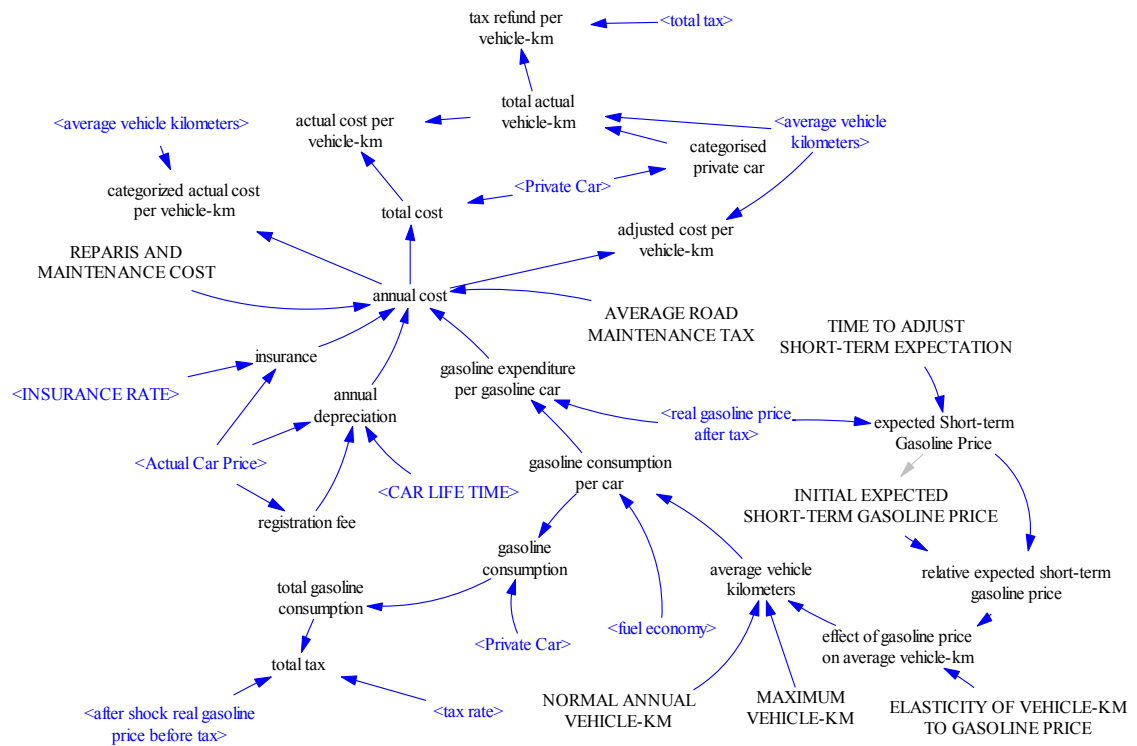
1.6 Willingness to Change Fuel Economy



1.7 Expected Fractional Growth Rate



1.8 Cost



Appendix 2 Equations and Documentation

2.1 Subscripts

area:

rural,urban

car:

price less than 50k, price 50k to 100k,price 100k to 160k,price 160k to 230k,price 230k to 300k,price 300k to 500k,price over 500k

efficiency:

fuel efficient, non fuel efficient

inco 110k to 160k:

(income 11-income 16)

inco 170k to 230k:

(income 17-income 23)

inco 240k to 300k:

(income 24-income 30)

inco 30K TO 50K:

(income 3-income 5)

inco 310k to 500k:

(income 31-income 50)

inco 60k to 100k:

(income 6-income 10)

inco over 500k:

income over 50

income class:

(income 1-income 50), income over 50

income price class:

income less than 30k,income 30k to 50k,income 60k to 100k,income 110k to 160k,income 170k to 230k,income 240k to 300k, income 310k to 500k, income over 500k

less than 30k:

income 1,income 2

sub efficiency:

sub1,sub2

2.2 Control Panel

Simulation Control Parameters

FINAL TIME = 2030

~ Year

~ The final time for the simulation.

INITIAL TIME = 1995

~ Year

~ The initial time for the simulation.

SAVEPER = 1

~ Year [0,?]

~ The frequency with which output is stored.

TIME STEP = 0.0625

~ Year [0,?]

~ The time step for the simulation.

2.3 Car Section

adjusted income level[income class]=

income class*income class size*(1-IF THEN ELSE(Time<2006, car tax rate 1994[income class], car tax rate 2006[income class]))

~ dmnl

~ income class*INCOME CLASS SIZE

adjustment time=

1.5

~ Year

~ even the consumer can afford a car, he still needs some time to search in the market which car to buy or when to buy

car tax rate 1994[income class]=

0.0458,0.0458,0.0458,0.0458,0.0458,0.0497,0.0497,0.0497,0.0497,0.0497,0.0503,0.0503,0.0503,0.0503,0.0503,0.0503,0.0568,0.0568,0.0568,0.0568,0.0568,0.0568,0.0568,0.0568,0.0665,0.0665,0.0665,0.0665,0.0665,0.0665,0.0665,0.0665,0.0698,0.0698,0.0698,0.0698

,0.0698,0.0698,0.0698,0.0698,0.0698,0.0698,0.0698,0.0698,0.0698,0.0698,0.0698,0.0698,0.0698,0.0698,0.0772

~ dmnl

car tax rate 2006[income class]=

0.03,0.03,0.03,0.03,0.03,0.0405,0.0405,0.0405,0.0405,0.0405,0.05,0.05,0.05,0.05,0.05,0.05,0.0589,0.0589,0.0589,0.0589,0.0589,0.0589,0.0589,0.0589,0.078,0.078,0.078,0.078,0.078,0.078,0.078,0.0946,0.0946,0.0946,0.0946,0.0946,0.0946,0.0946,0.0946,0.0946,0.0946,0.0946,0.0946,0.1477

~ dmnl

desired car for different price classification[price less than 50k]=

desired private ownership[income less than 30k]+desired private ownership[income 30k to 50k] ~|

desired car for different price classification[price 50k to 100k]=

desired private ownership[income 60k to 100k] ~|

desired car for different price classification[price 100k to 160k]=

desired private ownership[income 110k to 160k] ~|

desired car for different price classification[price 160k to 230k]=

desired private ownership[income 170k to 230k] ~|

desired car for different price classification[price 230k to 300k]=

desired private ownership[income 240k to 300k] ~|

desired car for different price classification[price 300k to 500k]=

desired private ownership[income 310k to 500k] ~|

desired car for different price classification[price over 500k]=

desired private ownership[income over 500k]

~ vehicle

~ assume they will buy cars in a range according to their income class, not outside that range

desired private ownership[income price class]=

desired private ownership per household[income price class]*households in income classes [income price class]

~ vehicle

desired private ownership per household[income less than 30k]=

SUM(desired private ownership per household table(adjusted income level[less than 30k!]))/2 ~|

desired private ownership per household[income 30k to 50k]=

SUM(desired private ownership per household table(adjusted income level[income 30K TO 50K!]))/3 ~|

desired private ownership per household[income 60k to 100k]=

SUM(desired private ownership per household table(adjusted income level[income

60k to 100k!))/5 ~|
 desired private ownership per household[income 110k to 160k]=
 SUM(desired private ownership per household table(adjusted income level[inco
 110k to 160k!]))/6 ~|
 desired private ownership per household[income 170k to 230k]=
 SUM(desired private ownership per household table(adjusted income level[inco
 170k to 230k!]))/7 ~|
 desired private ownership per household[income 240k to 300k]=
 SUM(desired private ownership per household table(adjusted income level[inco
 240k to 300k!]))/7 ~|
 desired private ownership per household[income 310k to 500k]=
 SUM(desired private ownership per household table(adjusted income level[inco
 310k to 500k!]))/20 ~|
 desired private ownership per household[income over 500k]=
 SUM(desired private ownership per household table(adjusted income level[inco
 over 500k!]))
 ~ vehicle/household

desired private ownership per household table(
 [(0,0)-(600000,1.5)],(0,0),(11315,0.00109649),(16055,0.00285088),(19419,0.008
 11404),(21406.7,0.0162281),(29357.8,0.0504386),(62385.3,0.216228),(121101,0.697
 368),(166972,1.11842),(201835,1.27632),(247706,1.40789),(427523,1.45),(572477,1.
 5))

~ vehicle/household

~ State Information Centre of China

[(0,0)-(600000,1.5)],(0,0),(11315,0.00109649),(16055,0.00285088),(19419,0.008
 11404),(21406.7,0.0162281),(29357.8,0.0504386),(62385.3,0.216228),(121101,0.697
 368),(166972,1.11842),(201835,1.27632),(247706,1.40789),(427523,1.45),(572477,1.
 5)

Do1

[(0,0)-(600000,1.5)],(0,0),(11315,0.00109649),(16055,0.00285088),(19419,0.008
 11404),(36697.2,0.0263158),(62385.3,0.0921053),(100917,0.348684),(135780,0.638
 158),(172477,0.986842),(240367,1.23026),(422018,1.34868),(565138,1.38158)

Do2

[(0,0)-(600000,1.7)],(0,0),(11315,0.00109649),(16055,0.00285088),(19419,0.008
 11404),(21406.7,0.0162281),(29357.8,0.0504386),(49541.3,0.260965),(110092,0.767
 982),(161468,1.24518),(201835,1.45395),(427523,1.52851),(570642,1.5807)

effect of fuel efficient car sales on technology investment=

effect of fuel efficient car sales on technology investment table(relative fuel
 efficient car market share)

~ dmn1

effect of fuel efficient car sales on technology investment table(

[(0,0)-(3,5)],(0.192661,0.570175),(0.504587,0.570175),(0.816514,0.767544),(1,1),
 (1.26605,1.42544),(1.45872,1.95175),(1.56881,2.43421),(1.68807,3.11404),(1.76147,
 3.57456),(1.86239,3.99123),(1.94495,4.27632),(2.09174,4.47368),(2.25688,4.62719),
 (2.38532,4.67105),(2.55963,4.71491),(2.70642,4.75877),(2.87156,4.75877))
 ~ dmnl

effect of gas price on tech investment=

"relative expected long-term gasoline price"^{elasticity of tech investment to gas price}

~ dmnl

elasticity of tech investment to gas price=

0.2

~ dmnl

expected annual depreciation[car,efficiency]=

(expected car price[car,efficiency]+expected registration fee[car,efficiency])/car life time

~ yuan97/vehicle/Year

expected car price[car,efficiency]=

DELAY N(actual car price[car,efficiency], 1, actual car price[car,efficiency], 1)

~ yuan97/vehicle

expected gasoline expenditure per car[car,efficiency]=

fuel economy[car,efficiency]*"normal annual vehicle-km"[car]/100*"expected long-term gasoline price"

~ yuan97/vehicle/Year

expected insurance[car,efficiency]=

400+expected car price[car,efficiency]*insurance rate+1300

~ yuan97/vehicle/Year

~ basic insurance for vehicle damage

expected main cost[car,efficiency]=

expected annual depreciation[car,efficiency]+expected gasoline expenditure per car[car,efficiency]+expected insurance[car,efficiency]

~ yuan97/vehicle/Year

expected registration fee[car,efficiency]=

expected car price[car,efficiency]*0.1

~ yuan97/vehicle

fractional tech investment rate=

initial fractional investment rate*effect of fuel efficient car sales on technology investment*effect of gas price on tech investment

~ dmn1

~ INITIAL FRACTIONAL INVESTMENT RATE*effect of fuel efficient car sales on technology investment

fuel efficient car market share=

(SUM(fuel efficient car purchase[car!,efficiency!])/2)/SUM(private car purchase[car!,efficiency!])

~ dmn1

~ SUM(private car purchase[car!,FUEL EFFICIENT])/SUM(private car purchase[car!,efficiency!])

fuel efficient car purchase[car,efficiency]=

IF THEN ELSE(perceived fuel economy of new car[car,fuel efficient]<perceived fuel economy of new car [car,non fuel efficient], private car purchase[car,fuel efficient], private car purchase[car,non fuel efficient])

~ vehicle/Year

gini coefficient[rural]=

rural gini coefficient table(Time) ~|

gini coefficient[urban]=

urban gini coefficient table(Time)

~ dmn1

household number[rural]=

rural household number table(Time) ~|

household number[urban]=

urban household number table(Time)

~ household

households in income classes[income price class]=

SUM(household number[area!]*share of households in different income classes[area!,income price class])

~ household

income class size=

10000

~ dmn1

income level[income class]=

income class*income class size

~ dmn1

initial fractional investment rate=

0.0063

~ dmnl

initial fuel efficient car market share= INITIAL(
fuel efficient car market share)

~ dmnl

initial private car[car]=

1.10764e+006, 32846, 1000, 10, 0, 0, 0

~ vehicle

initial private car of different fuel efficiency[car,fuel efficient]=

initial private car[car]*initial share of fuel efficient cars[car] ~|

initial private car of different fuel efficiency[car,non fuel efficient]=

initial private car[car]*(1-initial share of fuel efficient cars[car])

~ vehicle

initial share of fuel efficient cars[car]=

0.39, 0.35, 0.26, 0.1, 0.13, 0.04, 0.009

~ dmnl

mean real disposable income per household[rural]=

mean real disposable income per rural household table(Time) ~|

mean real disposable income per household[urban]=

mean real disposable income per urban household table(Time)

~ yuan97/household/Year

mean real disposable income per rural household table(

[(1995,0)-(2030,60000)],(1995,7863.55),(1996,8749.56),(1997,9091.93),(1998,9
371.66),

(1999,9604.62),(2000,9638.7),(2001,9932.53),(2002,10425.2),(2003,10831.3),(2
004,11615.3),(2030.43,40702.6))

~ yuan97/household/Year

~ Base

[(1995,0)-(2030,60000)],(1995,7863.55),(1996,8749.56),(1997,9091.93),(1998,9
371.66),(1999,9604.62),(2000,9638.7),(2001,9932.53),(2002,10425.2),(2003,10831.3
,)(2004,11615.3),(2030.43,40702.6)

Eco1

[(1995,0)-(2030,60000)],(1995,7863.55),(1996,8749.56),(1997,9091.93),(1998,9
371.66),(1999,9604.62),(2000,9638.7),(2001,9932.53),(2002,10425.2),(2003,10831.3
,)(2004,11615.3),(2030.43,21488.5)

Eco2

[(1995,0)-(2030,60000)],(1995,7863.55),(1996,8749.56),(1997,9091.93),(1998,9371.66),(1999,9604.62),(2000,9638.7),(2001,9932.53),(2002,10425.2),(2003,10831.3),(2004,11615.3),(2030.43,57864.9)

mean real disposable income per urban household table(

[(1995,0)-(2030,200000)],(1995,15391),(1996,15914.1),(1997,16461.4),(1998,17281.7),(1999,18794.2),(2000,20018.6),(2001,21507.2),(2002,23876.9),(2003,25691.9),(2004,27220.4),(2030,181034))

~ yuan97/household/Year

~ Base

[(1995,0)-(2030,200000)],(1995,15391),(1996,15914.1),(1997,16461.4),(1998,17281.7),(1999,18794.2),(2000,20018.6),(2001,21507.2),(2002,23876.9),(2003,25691.9),(2004,27220.4),(2030,181034)

Eco1

[(1995,0)-(2030,200000)],(1995,15391),(1996,15914.1),(1997,16461.4),(1998,17281.7),(1999,18794.2),(2000,20018.6),(2001,21507.2),(2002,23876.9),(2003,25691.9),(2004,27220.4),(2030,97436.5)

Eco2

[(1995,0)-(2030,400000)],(1995,15391),(1996,15914.1),(1997,16461.4),(1998,17281.7),(1999,18794.2),(2000,20018.6),(2001,21507.2),(2002,23876.9),(2003,25691.9),(2004,27220.4),(2030,257566)

perceived fuel economy of new car[car,efficiency]=

DELAY N(fuel economy of new car[car,efficiency], 0.06, initial fuel economy[car,efficiency], 1)

~ l/km

profit=

total revenue*average profit margin

~ yuan97/Year

~ ~ :SUPPLEMENTARY

propensity to purchase fuel efficient car for the same price range[car,fuel efficient]=

EXP(-Logit parameter*relative main cost[car,fuel efficient])/SUM(EXP(-Logit parameter*relative main cost[car,efficiency!]))

~ dmnl

reference cost=

1000

~ yuan97/Year/vehicle

reference income=

1

~ yuan97/household/Year

relative fractional tech investment rate=

fractional tech investment rate-initial fractional investment rate
 ~ dmnl

relative fuel efficient car market share=

fuel efficient car market share/initial fuel efficient car market share
 ~ dmnl

relative main cost[car,efficiency]=

expected main cost[car,efficiency]/reference cost
 ~ dmnl

relative mean real disposable income per household[area]=

mean real disposable income per household[area]/reference income
 ~ dmnl

revenue[car,efficiency]=

actual car price[car,efficiency]*private car purchase[car,efficiency]
 ~ yuan97/Year

rural gini coefficient table(

[(1995,0)-(2030,0.5)],(1995,0.33),(1996,0.3362),(1999,0.3539),(2001,0.3633),(2030,0.421053))
 ~ dmnl

rural household number table(

[(1995,1.8e+008)-(2030,2e+008)],(1995,1.91846e+008),(1996,1.925e+008),(1997,1.9351e+008),(1998,1.93379e+008),(1999,1.93031e+008),(2000,1.92469e+008),(2001,1.91718e+008),(2002,1.89446e+008),(2003,1.87441e+008),(2004,1.85551e+008),(2030,1.86429e+008))
 ~ household

share of households below different income level[area,income class]=

min(1,LNNORMAL(1, income level[income class], relative mean real disposable income per household[area], standard deviation of household income [area]))
 ~ dmnl

share of households in different income classes[area, income less than 30k]=

share of households below different income level[area,income 3] ~|

share of households in different income classes[area,income 30k to 50k]=

share of households below different income level[area,income 6]-share of households below different income level[area,income 3] ~|

share of households in different income classes[area,income 60k to 100k]=
 share of households below different income level[area,income 11]-share of
 households below different income level[area,income 6] ~|
 share of households in different income classes[area,income 110k to 160k]=
 share of households below different income level[area,income 17]-share of
 households below different income level[area,income 11] ~|
 share of households in different income classes[area,income 170k to 230k]=
 share of households below different income level[area,income 24]-share of
 households below different income level[area,income 17] ~|
 share of households in different income classes[area,income 240k to 300k]=
 share of households below different income level[area,income 31]-share of
 households below different income level[area,income 24] ~|
 share of households in different income classes[area,income 310k to 500k]=
 share of households below different income level[area,income over 50]-share of
 households below different income level[area,income 31] ~|
 share of households in different income classes[area,income over 500k]=
 max(0,(1-share of households below different income level[area,income over
 50]))
 ~ dmn1

standard deviation of household income[area]=
 standard deviation over mean ratio table(gini coefficient[area])*relative mean real
 disposable income per household[area]
 ~ dmn1

standard deviation over mean ratio table(
 [(0,0)-(0.8,6)],(0.0518,0.1),(0.109,0.2),(0.1628,0.3),(0.2133,0.4),(0.2605,0.5),(0.3
 04,0.6),(0.3428,0.7),(0.3801,0.8),(0.413,0.9),(0.4429,1),(0.47,1.1),(0.5554,1.5),(0.627
 ,2),(0.7103,3),(0.7572,4),(0.7874,5))
 ~ dmn1

total private car=
 SUM(private car[car!,efficiency!])
 ~ vehicle

total revenue=
 SUM(revenue[car!,efficiency!])
 ~ yuan97/Year

urban gini coefficient table(
 [(1995,0)-(2030,0.5)],(1995.05,0.285965),(1996,0.2909),(1999,0.3155),(2001,0.3
 332),(2030.11,0.403509))
 ~ dmn1

urban household number table(

[(1995,0)-(2030,4e+008)],(1995,1.08898e+008),(1996,1.16575e+008),(1997,1.23665e+008),(1998,1.31671e+008),(1999,1.39325e+008),(2000,1.46665e+008),(2001,1.55045e+008),(2002,1.65171e+008),(2003,1.74007e+008),(2004,1.82158e+008),(2030,2.65833e+008))

~ household

2.4 Cost Section

actual car price[car,efficiency]=

DELAY N(SUM(indicated car price[car,efficiency,sub efficiency!])/2, 3, SUM(indicated car price[car,efficiency,sub efficiency!])/2, 1)

~ yuan97/vehicle

"actual cost per vehicle-km"=

total cost/"total actual vehicle-km"

~ yuan97/km

after shock real gasoline price before tax=

real gasoline price before tax*price shock

~ yuan97/l

annual cost[car,efficiency]=

annual depreciation[car,efficiency]+average road maintenance tax+gasoline expenditure per gasoline car[car,efficiency]+ insurance[car,efficiency]+reparis and maintenance cost

~ yuan97/vehicle/Year

annual depreciation[car,efficiency]=

(actual car price[car,efficiency]+registration fee[car,efficiency])/car life time

~ yuan97/vehicle/Year

average car price[car]=

40000,75000,130000,195000,265000,400000,650000

~ yuan97/vehicle

average road maintenance tax=

1500+average road maintenance tax shock

~ yuan97/vehicle/Year

average road maintenance tax shock=

STEP(-1500, 2007)*0

~ yuan97/vehicle/Year

~ according to <http://mall.chinacars.com/list1.asp> Fee List for Driving

Shanghai/ Guandong/ Beijing Road Management Administrative

average vehicle kilometers[car]=

min("maximum vehicle-km"[car],"normal annual vehicle-km"[car]*"effect of gasoline price on average vehicle-km"[car])

~ km/vehicle/Year

car life time=

10

~ Year

~ according to vehicle retirement standard and own estimation

categorised private car[car]=

SUM(private car[car,efficiency!])

~ vehicle

"effect of gasoline price on average vehicle-km"[car]=

"relative expected short-term gasoline price"^^"elasticity of vehicle-km to gasoline price" [car]

~ dmn1

"elasticity of vehicle-km to gasoline price"[car]=

-0.4,-0.4,-0.3,-0.3,-0.2,-0.1,-0.05

~ dmn1

~ according to literatures:

1.The Long-run Structure of Transportation and Gasoline Demand

2.Elasticities of road Traffic and Fuel Consumption with Respect to price and

Income: A Review

"expected short-term gasoline price"=

DELAY N(real gasoline price after tax, "time to adjust short-term expectation", real gasoline price after tax, 1)

~ yuan97/l

fuel economy[car,efficiency]=

IF THEN ELSE(private car[car,efficiency]>0, fuel consumption of cars on road[car,efficiency]/private car[car,efficiency], initial fuel economy[car,efficiency])

~ l/km

gasoline consumption[car]=

SUM(gasoline consumption per car[car,efficiency!]*private car[car,efficiency!])

~ l/Year

gasoline consumption per car[car,efficiency]=

average vehicle kilometers[car]*fuel economy[car,efficiency]/100
 ~ l/vehicle/Year

gasoline expenditure per gasoline car[car,efficiency]=
 gasoline consumption per car[car,efficiency]*real gasoline price after tax
 ~ yuan97/vehicle/Year

indicated car price[car,efficiency,sub1]=
 max(minimum car price[car],min(maximum car price[car],average car
 price[car]*(expected average fuel economy of new car[car]/expected fuel economy of
 new car[car,efficiency]))) ~|

indicated car price[car,efficiency,sub2]=
 min(maximum car price[car],max(minimum car price[car],average car
 price[car]*(expected average fuel economy of new car[car]/initial fuel
 economy[car,efficiency])))
 ~ yuan97/vehicle

"initial expected short-term gasoline price"= INITIAL(
 "expected short-term gasoline price")
 ~ yuan97/l

insurance[car,efficiency]=
 400+actual car price[car,efficiency]*insurance rate+1300
 ~ yuan97/vehicle/Year
 ~ basic insurance for vehicle damage

insurance rate=
 0.012
 ~ dml/Year

"maximum vehicle-km"[car]=
 40000,40000,40000,40000,40000,40000,40000
 ~ km/vehicle/Year

"normal annual vehicle-km"[car]=
 10000,15000,15000,20000,20000,25000,25000
 ~ km/vehicle/Year
 ~

http://www.che168.com/article/html/200605/20060529/20060529_131408_1.htm

l influence of gasoline price on car purchasing

<1.0L	5.34L/100km	6000km-12000km/year	normaly
10000km/year			
1.0-1.3L	5.7L/100km	8000km-15000km/year	12000km/year

1.3-1.6L	6.89L/100km	10000-18000km/year	15000km/year
taxi:60000-100000km/year main stream of private vehicle			
1.6-2.0L	8.54L/100km	15000-60000km/year	40000km/year for private, government and corporate vehicle
2.0-2.5L	9.54L/100km	20000-50000km/year	30000km/year luxury vehicles
>2.5L	11.37L/100km	15000-40000km/year	25000km/year super luxury vehicle 2% market
SUV	11.9L/100km	40000-70000km/year	50000km/year
Crossover	11.59L/100km	10000-25000km/year	
MPV	9.99L/100km	30000-60000km/year	40000km/year

private car[car,efficiency]= INTEG (
 private car purchase[car,efficiency]-private car scrappage[car,efficiency],
 initial private car of different fuel efficiency[car,efficiency])
 ~ vehicle

real gasoline price after tax=
 after shock real gasoline price before tax*(1+tax rate)

registration fee[car,efficiency]=
 actual car price[car,efficiency]*0.1
 ~ yuan97/vehicle

"relative expected short-term gasoline price"=
 "expected short-term gasoline price"/"initial expected short-term gasoline price"
 ~ dmdl

reparis and maintenance cost=
 5500
 ~ yuan97/vehicle/Year

"standard cost per vehicle-km"=
 total cost/"total normal vehicle-km"
 ~ yuan97/km

tax rate=
 STEP(1, 2007)-STEP(1, 2015)
 ~ dmdl
 ~ 0
 STEP(1, 2007)-STEP(1, 2015)

"time to adjust short-term expectation"=

1.5
 ~ Year

"total actual vehicle-km"=
 SUM(average vehicle kilometers[car!]*categorised private car[car!])
 ~ km/Year

total cost=
 SUM(annual cost[car!,efficiency!]*private car[car!,efficiency!])
 ~ yuan97/Year

total gasoline consumption=
 SUM(gasoline consumption[car!])
 ~ l/Year

total gasoline expenditure without tax=
 total gasoline consumption*after shock real gasoline price before tax
 ~ yuan97/Year
 ~ ~ :SUPPLEMENTARY

"total normal vehicle-km"=
 SUM("normal annual vehicle-km"[car!]*categorised private car[car!])
 ~ km/Year

total tax=
 after shock real gasoline price before tax*tax rate*total gasoline consumption
 ~ yuan97/Year

2.5 Expectation Section

Change in PPC[car,efficiency]=
 (INPUT[car,efficiency] - "Perceived Present Condition
 (PPC)"[car,efficiency])/Time to Perceive Present Condition (TPPC)"
 ~ vehicle/Year/Year
 ~ The perceived present condition adjusts to the actual value of the input
 via first-order smoothing, with a time constant given by TPPC.

Change in RC[car,efficiency]=
 ("Perceived Present Condition (PPC)"[car,efficiency] - "Reference Condition
 (RC)"[car,efficiency])/Time Horizon for Reference Condition (THRC)"
 ~ vehicle/Year/Year
 ~ The reference condition adjusts via first-order smoothing to the perceived
 present condition, with a time constant given by THRC, representing the historical
 horizon for trend calculation. The longer THRC, the farther back in history the

decision makers consider when estimating growth rates.

Change in TREND[car,efficiency]=

("Indicated Trend (ITREND)" [car,efficiency]- "Perceived Trend (TREND)"[car,efficiency])/("Time to Perceive Trend (TPT)"

~ 1/(Year*Year)

~ The perceived trend adjusts via first-order smoothing to the indicated value, with a time constant given by TPT.

expected fractional growth rate[car,efficiency]=

OUTPUT[car,efficiency]

~ 1/Year

"Indicated Trend (ITREND)"[car,efficiency]=

ZIDZ(("Perceived Present Condition (PPC)" [car,efficiency]-"Reference Condition (RC)"[car,efficiency]), ("Reference Condition (RC)"[car,efficiency]*"Time Horizon for Reference Condition (THRC)"

~ 1/Year

~ The indicated TREND is the growth rate of the input indicated now based on the reference condition and the perceived present condition. It may take time for decision makers to recognize and respond to this value. The indicated trend yields an unbiased estimate, in steady state, of the fractional growth rate in the input.

("perceived Present Condition (ppc)" [car,efficiency]-"reference Condition (rc)"[car,efficiency])/("reference Condition (rc)"[car,efficiency]*"TIME HORIZON FOR REFERENCE CONDITION (THRC)"

INPUT[car,efficiency]=

private car purchase[car,efficiency]

~ vehicle/Year

~ The input to the TREND function. Set for testing purposes to an exponential.

OUTPUT[car,efficiency]=

"Perceived Trend (TREND)"[car,efficiency]

~ 1/Year

~ The output of the TREND function is simply the perceived trend.

"Perceived Present Condition (PPC)"[car,efficiency]= INTEG (

Change in PPC[car,efficiency],INPUT[car,efficiency]/(1+"Perceived Trend (TREND)"[car,efficiency]*"Time to Perceive Present Condition (TPPC)")

~ vehicle/Year

~ The perceived present condition of the input lags behind the true input to capture data reporting and perception delays. Set initially in the steady state given the user-supplied initial value of the perceived trend.

"Perceived Trend (TREND)"[car,efficiency]= INTEG (

Change in TREND[car,efficiency],0)

~ 1/Year

~ The Perceived TREND is the decision makers' belief about the current \

fractional rate of change in the input.

private car purchase[car,fuel efficient]=

(max(0,(desired car for different price classification[car]-SUM(private

car[car,efficiency!])))/adjustment time+SUM(private car

scrappage[car,efficiency!]))*propensity to purchase fuel efficient car for the same

price range[car,fuel efficient] ~|

private car purchase[car,non fuel efficient]=

(max(0,(desired car for different price classification[car]-SUM(private

car[car,efficiency!])))/adjustment time+SUM(private car

scrappage[car,efficiency!]))*(1-propensity to purchase fuel efficient car for the same

price range[car,fuel efficient])

~ vehicle/Year

"Reference Condition (RC)"[car,efficiency]= INTEG (

Change in RC[car,efficiency],

"Perceived Present Condition (PPC)"[car,efficiency]/(1+"Perceived Trend

(TREND)"[car ,efficiency]*"Time Horizon for Reference Condition (THRC)"))

~ vehicle/Year

~ The reference condition is an exponentially weighted average of the past

values of the perceived present condition. It represents the value of the input THRC

periods in the past. Set initially in the steady state given the user-supplied initial

value of the perceived trend.

"Time Horizon for Reference Condition (THRC)"=

1

~ Year

~ The long the time horizon, the more short-term variation in the growth rate of

the input will be filtered out by the TREND function.

"Time to Perceive Present Condition (TPPC)"=

0.25

~ Year

~ The average lag in the reporting and perception of the input.

"Time to Perceive Trend (TPT)"=

0.25

~ Year

~ The time required for decision makers to adjust their beliefs and reports to

the indicated trend. Represents report preparation and perception delays in the adjustment of growth expectations to new information.

2.6 Fuel Economy Section

annual transition cost=

$$\frac{\text{product line transition cost}}{\text{product life time}}$$

~ yuan97/Year

average fuel economy=

$$\frac{\text{SUM}(\text{fuel economy}[\text{car!},\text{efficiency!}] * \text{private car}[\text{car!},\text{efficiency!}])}{\text{SUM}(\text{private car}[\text{car!},\text{efficiency!}])}$$

~ l/km
 ~ ~ :SUPPLEMENTARY

average fuel economy of new car[car]=

$$\frac{\text{SUM}(\text{fuel economy of new car}[\text{car},\text{efficiency!}])}{2}$$

~ l/km

average profit margin=

$$\frac{\text{initial average profit margin} - \text{relative fractional tech investment rate}}{\text{dmnl}}$$

desired fuel economy=

$$\frac{\text{initial desired fuel economy} * \text{"relative expected long-term gasoline price"}^{\text{elasticity of fuel economy to gasoline price}}}{\text{dmnl}}$$

elasticity of fuel economy to gasoline price=

$$-0.3$$

~ dmnl

expected average fuel economy of new car[car]=

$$\text{DELAY } N(\text{average fuel economy of new car}[\text{car}], 3, \text{SUM}(\text{initial fuel economy}[\text{car},\text{efficiency!}])/2, 1)$$

~ l/km

expected demand[car,efficiency]=

$$\text{private car purchase}[\text{car},\text{efficiency}] * (1 + \text{expected fractional growth rate}[\text{car},\text{efficiency}] * \text{reference time})^{(\text{time to apply tech on product line}/\text{reference time})}$$

~ vehicle/Year

expected fuel economy of new car[car,efficiency]=

initial fuel economy[car,efficiency]*max(desired fuel economy,relative fuel economy of prototype)
 ~ l/km

"expected long-term gasoline price"=
 DELAY N(real gasoline price after tax, "time to adjust long-term expectation",
 real gasoline price after tax, 1)
 ~ yuan97/1

fuel consumption discard on road[car,efficiency]=
 fuel economy[car,efficiency]*private car scrappage[car,efficiency]
 ~ l*vehicle/(Year*km)

fuel consumption improvement of new car=
 (max(relative fuel economy of prototype,desired fuel economy)-relative fuel economy of new car)/time to apply tech on product line
 ~ dml/Year

fuel consumption improvement on road[car,efficiency]=
 fuel economy of new car[car,efficiency]*private car purchase[car,efficiency]
 ~ (l/km)*(vehicle/Year)

fuel consumption of cars on road[car,efficiency]= INTEG (
 fuel consumption improvement on road[car,efficiency]-fuel consumption discard on road[car,efficiency],
 initial fuel economy[car,efficiency]*private car[car,efficiency])
 ~ l*vehicle/km

fuel economy of new car[car,efficiency]=
 initial fuel economy[car,efficiency]*relative fuel economy of new car*willingness to change fuel economy[car,efficiency,sub1]+initial fuel economy[car,efficiency]*(1-willingness to change fuel economy[car,efficiency,sub1])
 ~ l/km

indicated profit[car,efficiency,sub1]=
 indicated revenue[car,efficiency,sub1]-annual transition cost-production cost per car [car]*expected demand[car,efficiency] ~|

indicated profit[car,efficiency,sub2]=
 indicated revenue[car,efficiency,sub2]-production cost per car[car]*expected demand[car,efficiency]
 ~ yuan97/Year

indicated relative fuel consumption=

relative tech cost table(tech investment allocation/initial cost for new prototype)
 ~ dmn1

indicated revenue[car,efficiency,sub efficiency]=
 indicated car price[car,efficiency,sub efficiency]*expected demand[car,efficiency]
 ~ yuan97/Year

initial average profit margin=
 0.06
 ~ dmn1

initial cost for new prototype=
 8e+009
 ~ yuan97

initial desired fuel economy=
 1
 ~ dmn1

"initial expected long-term gasoline price"= INITIAL(
 "expected long-term gasoline price")
 ~ yuan97/l

initial fuel economy[car,fuel efficient]=
 7.29,9.03,10.02,11.538,11.538,12.8,13.325 ~|
 initial fuel economy[car,non fuel efficient]=
 9.945,11.16,11.88,14.76,13.275,14.93,15.21
 ~ l/km
 ~ China industrial statistics yearbook

Logit parameter=
 0.5
 ~ dmn1

maximum car price[car]=
 60000,120000,190000,270000,360000,600000,800000
 ~ yuan97/vehicle
 ~ 50000,100000,160000,230000,300000,500000,1e+006

minimum car price[car]=
 30000,50000,90000,140000,200000,280000,450000
 ~ yuan97/vehicle

price shock=

1+STEP(1,2015)

~ dmdl

~ 1

1+STEP(1,2015)

private car scrappage[car,efficiency]=

private car[car,efficiency]/car life time

~ vehicle/Year

product life time=

3

~ Year

product line transition cost=

1e+008

~ yuan97

~ retrofit or substitution

production cost per car[car]=

average car price[car]*(1-average profit margin)

~ yuan97/vehicle

real gasoline price before tax= WITH LOOKUP (

Time,

((1995,0)-(2030,10]),(1995,2.44759),(1996,2.33873),(1997,2.33873),(1998,2.33873),(1999,2.43342),(2000,3.03492),(2001,2.92295),(2002,2.87544),(2003,3.16346),(2004,3.45147),(2005,3.8),(2006,4.7))

~ yuan97/l

reference profit=

1e+010

~ yuan97/Year

reference time=

1

~ Year

"relative expected long-term gasoline price"=

"expected long-term gasoline price"/"initial expected long-term gasoline price"

~ dmdl

relative fuel economy of new car= INTEG (

fuel consumption improvement of new car,1)

~ dmn1

relative fuel economy of prototype= INTEG (tech improvement,1)

~ dmn1

relative profit[car,efficiency,sub efficiency]= indicated profit[car,efficiency,sub efficiency]/reference profit

~ dmn1

relative tech cost table(

[(0,0)-(40,1)],(0.336391,0.97807),(0.489297,0.97807),(0.678899,0.969298),(0.831804,0.95614),(0.978593,0.929825),(1.59021,0.877193),(2.93578,0.745614),(5.99388,0.587719),(8.31804,0.52193),(12.1101,0.45614),(16.1468,0.416667),(21.2844,0.368421),(26.422,0.342105),(30.0917,0.324561),(34.3731,0.311404),(38.2875,0.311404)

~ dmn1

~

[(0,0)-(40,1)],(0.336391,0.97807),(0.489297,0.97807),(0.678899,0.969298),(0.831804,0.95614),(0.978593,0.929825),(1.59021,0.877193),(2.93578,0.745614),(5.99388,0.587719),(8.31804,0.52193),(12.1101,0.45614),(16.1468,0.416667),(21.2844,0.368421),(26.422,0.342105),(30.0917,0.324561),(34.3731,0.311404),(38.2875,0.311404)

Tc1

[(0,0)-(40,1)],(0.336391,0.97807),(0.489297,0.97807),(0.678899,0.969298),(0.831804,0.95614),(0.978593,0.947368),(2.56881,0.877193),(4.64832,0.780702),(7.95107,0.662281),(10.6422,0.583333),(13.4557,0.513158),(17.1254,0.464912),(21.1621,0.421053),(26.422,0.385965),(30.2141,0.368421),(34.4954,0.355263),(38.2875,0.337719)

Tc2

[(0,0)-(40,1)],(0.336391,0.97807),(0.489297,0.97807),(0.678899,0.969298),(0.831804,0.95614),(0.831804,0.934211),(0.978593,0.877193),(1.83486,0.732456),(4.89297,0.565789),(7.5841,0.486842),(11.9878,0.407895),(15.9021,0.350877),(21.2844,0.302632),(26.422,0.27193),(30.2141,0.236842),(34.2508,0.22807),(38.4098,0.210526)

tech improvement=

(indicated relative fuel consumption-relative fuel economy of prototype)/time to develop tech

~ dmn1/Year

tech investment allocation=

DELAY N(technology investment rate, time to allocate tech investment, technology investment rate, 2)

~ yuan97/Year

~ DELAY N(technology investment rate, TIME TO ALLOCATE TECH

INVESTMENT, technology investment rate, 2)

DELAY N(technology investment rate+total tax/2, TIME TO ALLOCATE
TECH INVESTMENT, technology investment rate+total tax/2, 2)

technology investment rate=

total revenue*fractional tech investment rate
~ yuan97/Year

"time to adjust long-term expectation"=

3
~ Year

time to allocate tech investment=

2
~ Year

time to apply tech on product line=

3
~ Year
~ 3
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time to develop tech=

5
~ Year

willingness to change fuel economy[car,efficiency,sub1]=

EXP(Logit parameter*relative profit[car,efficiency,sub1])/SUM(EXP(Logit
parameter*relative profit[car,efficiency,sub efficiency!]))
~ dmnl