

External Effects on Dynamic Competitive Model of Domestic Airline and High Speed Rail

Shih-Ching Lo, Yu-Ping Liao

Abstract—Social-economic variables influence transportation demand largely. Analyses of discrete choice model consider social-economic variables to study traveler's mode choice and demand. However, to calibrate the discrete choice model needs to have plenty of questionnaire survey. Also, an aggregative model is proposed. The historical data of passenger volumes for high speed rail and domestic civil aviation are employed to calibrate and validate the model. In this study, models with different social-economic variables, which are oil price, GDP per capita, CPI and economic growth rate, are compared. From the results, the model with the oil price is better than models with the other social-economic variables.

Keywords—forecasting, passenger volume, dynamic competitive model, social-economic variables, oil price.

I. INTRODUCTION

TRANSPORTATION demand is a derived demand, which follows the growth of the economy. The level and structure of economic activity influence the volume of transportation systems. Therefore, social-economic variable, such as GDP, income or economical indexes, should be considered in a predictive model of transportation demand. From another point of view, economic activity requires a certain amount of transport. The development of modern cities also depends on the natural transportation corridors, such as rivers and harbors, and transportation infrastructures. There exists strong interrelationship between transportation and social-economic systems. In Taiwan, freeway coach, railway and domestic airline provide the intercity transportation of the western corridor before 2007. Taiwan High-Speed Rail (THSR) starts its service and joins the competition in the corridor on January 5, 2007. Buckeye [1] considered that intercity distance range of 100~400 miles high-speed rail and air carriers can both serve the passengers, whereas Kanafani and Youssef [2] considered the intercity distance range of 220~620 miles. In 2005, Lin et al. [3] estimated that approximately 50% of the air trips, 20% of Taiwan Rail Administration (TRA) trips, and 15% of freeway coach trips in Taiwan's western corridor would be replaced by THSR. A before-and-after comparison investigates passengers for the modal splits on Taiwan's western corridor regarding THSR's operations, 67.2% of air passengers, 47.6% of TRA passengers and 32.5% freeway coach travelers would change their mode of travel to THSR [4]. The results show that the three original modes of intercity transport are significantly affected by THSR, especially the domestic civil aviation service. The impact of THSR on air market is much larger than the prediction of related studies [5]-[7].

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Because of under estimation of the of THSR, airlines did not take suitable response to compete with THSR. Therefore, a robust forecasting model is necessary for transportation service operators so as to set up proper strategies or find out their niches to survive the keen competition.

Generally, regression method is the most used forecasting techniques. However, the predicted ability depends on the regression function and variables. Sometimes it is hardly to explain how the independent variables influence the dependent variables by the function. Time series analysis, which is also a common used method, might have the same problem. To analyze modal choice of transportation demand, discrete choice model is used mostly. By inquiring revealed and stated preference data, a Logit model or Probit model is built for analyzing modal split [8]-[12]. However, discrete choice model involve questionnaire survey, which takes time and money. If the external environment varies largely, such as financial tsunami in 2008, the prediction may also have large bias. Recently, Shyr and Hung [13] present a game theory based model to predict the competition between airline and THSR. They calibrate the payoff functions and solve the Nash equilibrium by maximizing payoff functions with respect to fare rates and flight frequency after the operation of THSR. They found that domestic airlines should unify as an alliance and cut their daily flights by 50% to maintain profitability.

In our previous result [14], a dynamic competitive model is proposed to predict the passenger volume of domestic airline and THSR in the western corridor of Taiwan. According to the results, systematic equations forecast better than single equations do. Models with the external variable, which is oil price, are better than models based on closed system assumption. Oil price influences the operational cost of airlines and usage of private transportation directly. However, there are still other social-economic variables, such as gross domestic product (GDP), income, economic growth rate and consumer price index (CPI). In this study, the influences of social-economic variables are compared and analyzed to find out the dominant external effect. The remaining content of this paper is organized as follows. In Sec. 2, the social-economic variables of Taiwan are discussed. Next, the background of domestic airlines and THSR are introduced briefly in Sec. 3. Dynamic competitive models are proposed and numerical results are presented in Sec. 4. Finally, the conclusion is drawn in Sec. 5.

II. SOCIAL-ECONOMIC FACTORS IN TAIWAN

The purchase power of individual may influence one's modal choice. Therefore, GDP per capita, income and CPI are

considered firstly. Income considered herein is nominal income (NI). Gross domestic product (GDP) refers to the monetary value of all finished final goods and services produced within a country in a given period. GDP per capita is often considered an indicator of a country's standard of living. Consumer price index (CPI) measures influence of price changes on cost of living. Nominal income (NI) is income stated without any adjustments for inflation, deflation, and other economic factors. It is stated in the monetary units of a given year. Fortunately, GDP per capita and NI have the same trend and the Pearson correlation coefficient of them is 1, which means GDP per capita and NI have linear relationship perfectly. Figure 1 shows the historical data of them. Therefore, we only consider GDP per capita between GDP per capita and NI in this study. In addition, the variation of economical situation should be considered. In this study, economic growth rate is employed. Hence, oil price, GDP per capita, CPI and economic growth rate are considered as the external social-economic effects in this study.

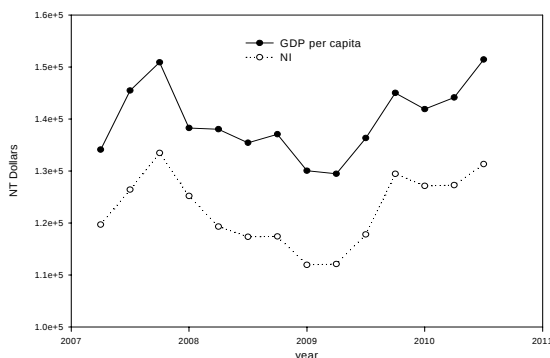


Fig. 1 Quarterly data of GDP per Capita and NI in New Taiwan Dollars (NT Dollars).

III. DOMESTIC AIRLINE AND THSR IN TAIWAN

In 1987, the Taiwan government carried out the deregulation policy, which is so-called "sky opening" policy. After that, the aviation market in Taiwan had considerably prospered until 1997. The number of passengers taking western airline had started to decline since 1998. Figure 2(a) illustrates the declining trend. One reason is the improvement of highway systems and the deregulation of freeway coach. Another reason is the domestic airlines expected the rapid opening of direct flights between Taiwan and Mainland China and airlines have made considerable investments in new planes during that time. Unfortunately, the preparedness has turned into a major financial burden before direct flights materializing. Expecting Soaring oil prices, industrial migration out of Taiwan and lackluster economic development on the island have also combined to reduce revenues. In addition, the operation of THSR is another reason of recession of domestic civil aviation industry. As a result, the domestic air travel market has shrunk and the THSR service is just another blow. Now, only the Mandarin Airlines, a subsidiary of Taiwan's China Airlines, still runs flights between Taipei and Kaohsiung, which once

three other local airlines was also operated.

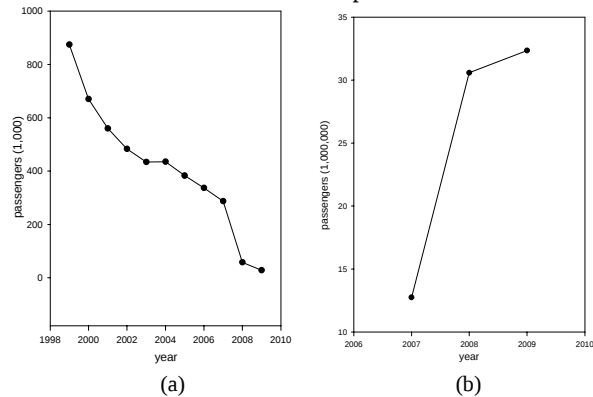


Fig. 2 Annual passenger volume of (a) domestic civil aviation and (b) THSR service in the western corridor of Taiwan.

Figure 3 illustrates the stations and the route of Taiwan High Speed Rail (abbreviated to THSR or HSR). Services of THSR began on January 5, 2007. It is a high-speed rail line that runs approximately 345 km (214 miles) along the west coast of Taiwan from the national capital of Taipei to the southern city of Kaohsiung (Zuoying station). The top operating speed is 300 km/h (186 mph), which offer journey times from Taipei to Zuoying as short as 96 minutes. In comparison, trains operating on the conventional Western Line of the Taiwan Railway Administration (TRA), take over four hours for the same journey. Surely, tickets of THSR are more expensive than those of normal trains or express buses, but cheaper than those for airplanes. Figure 2 (b) shows the annual passenger volumes from 2007 to 2009. The passenger volume grows from only 40,000 passengers a day to over 100,000 passengers a day in 2010. The original estimates foresaw a daily ridership of 180,000 passengers a day. A Taipei-Kaohsiung ticket on THSR costs NT\$1,490 (US\$45) is more expensive than TRA's NT\$845 (US\$25) and freeway coach's NT\$500 (US\$15), but it is cheaper than the fare of airplane, which costs 1,750 (US\$53). Although the line-haul travel time of airplane is less than it of THSR, the total travel time of THSR is less than it of airplane. It is because the THSR trains usually serve city centers, whereas airports are typically located on the urban fringe by necessity. THSR does pose a severe threat to domestic western civil aviation services.



Fig. 3 Stations and route of THSR. [15].

IV. DYNAMIC COMPETITION MODEL

The dynamic competitive model is consisted of two differential equations with interaction terms. Each of the systematic equations is extended from the population model. The simplest population model considered the growth rate of population is proportional to the population. Let $N(t)$ is the function of population and t is time. Then, we have $dN(t)/dt = \alpha N(t)$, where α is the proportional constant. The solution is given as

$$N(t) = N_0 e^{\alpha(t-t_0)}, \quad (1)$$

where t_0 is the initial time and N_0 is the initial population. However, the model can only to apply to short-term forecasting because when t increases N increases exponentially. The result is unreasonable. In real world, the growth of population is also proportional to the capacity of the system, that is, $dN(t)/dt \propto (M - N(t))$, where M is the capacity of system and is a constant. The model with the capacity restriction can also be solved analytically. The solution is in the logistic form, which is given by

$$N(t) = M / \left[1 + \left(\frac{M - N_0}{N_0} \right) e^{-\alpha M t} \right]. \quad (2)$$

Under the close system assumption, Eq. (2) can be represented by a general form, which is $dN(t)/dt = F(N, t)$. $F(N, t)$ is the growth function. If two species of population are considered, the model is consisted by two equations with interaction terms, such as $dN_1(t)/dt = F_1(N_1, N_2, t)$ and $dN_2(t)/dt = F_2(N_1, N_2, t)$, where N_1 and N_2 are two species, F_1 and F_2 are growth functions of N_1 and N_2 , respectively. The most famous model in this form is the Lotka-Volterra (LV) model [16]-[18], the model is given by

$$dN_1(t)/dt = a_1 N_1(t) + b_1 N_1^2(t) + c_1 N_1(t) N_2(t), \quad (3)$$

$$dN_2(t)/dt = a_2 N_2(t) + b_2 N_2^2(t) + c_2 N_1(t) N_2(t), \quad (4)$$

where a_1 , a_2 , b_1 , b_2 , c_1 and c_2 are coefficients. The multi-mode form of LV model is illustrated in Table I for the case of two species. Although there are five types of modes, note that there are two possible predator-prey interactions (depending on which species is the predator or prey) in predator-prey mode and two possible states (depending on which species is the stronger of the two) in amensalism model. Bass model [19]-[20] is a most used model for analyzing competition of two species or products. However, it is a parsimonious one which does not consider the competition factor in the market. Fisher and Pry [21] developed a simple substitution model based on the assumption that a new technology would displace an older established technology. The Fisher and Pry model also does not show their competition. Norton and Bass [22] took the Bass model as its core equation and incorporated the Fisher and Pry model to demonstrate the substitution effect. It can be used to forecast the diffusion of

new technologies. Among these, the mathematical Lotka-Volterra model was used in many papers and it could well explore the diffusion phenomenon and reciprocal competition of two species [23]-[27]. Furthermore, equations of the system are not restricted to two. If there are three or four species, the system can be extended to three or four equations.

TABLE I
THE RELATIONSHIP ACCORDING TO THE SIGNS OF c_1 AND c_2

coefficient		Type	Explanation
c_1	c_2		
-	-	Pure competition	Both species suffer from each other's existence.
+	-	Predator-prey	One of them serves as direct food (N_2) to the other (N_1).
+	+	Mutualism	It is the case of symbiosis or a win-win situation.
-	0	Amensalism	One (N_1) suffers from the existence of the other (N_2), who is impervious to what is happening.
0	0	Neutralism	There is no interaction

According to our previous result [14], the domestic aviation and THSR are in amensalism. That is, THSR is not influenced by domestic aviation; whereas, domestic aviation suffers from THSR. Oil price should be considered in the model. Since there are still three social-economic variables must be compared, the model is generalized as follows:

$$dN_1(t)/dt = a_1 N_1(t) + b_1 N_1^2(t) + c_1 N_1(t) N_2(t) + d_1 E_i(t), \quad (5)$$

$$dN_2(t)/dt = a_2 N_2(t) + b_2 N_2^2(t) + d_2 E_i(t), \quad (6)$$

where $E_i(t)$ denotes the external variables. Let $E_1(t)$ be the oil price, $E_2(t)$ be the GDP per capita, $E_3(t)$ be the CPI and $E_4(t)$ be the economic growth rate.

Figures 4 to 7 illustrate the comparison between actual and predicted data of Eqs (5) and (6) with $E_i(t)$, $i = 1, 2, 3, 4$. To obtain the models, we calibrate coefficients by historical data firstly. Then, the models can be used to forecast. Table II is the R-square value of each equation. External variables influence the R-square value of THSR largely, but do not influence the R-square value of airline. Model with oil price provides the highest R-square value for THSR. Table III gives the absolute percentage error. According to the results, model with economic growth rate presents a worse prediction obviously. Actually, the passenger volume predicted by the model with economic growth rate shows negative values, which is impossible in real world. Therefore, economic growth rate is not a good external variable to consider in the dynamic competitive model. Although the models with oil price, GDP per capita and CPI do not show significant difference, the predicted trend of model with oil price has the best agreement with historical data. Therefore, we suggest employing oil price in the dynamic competitive model.

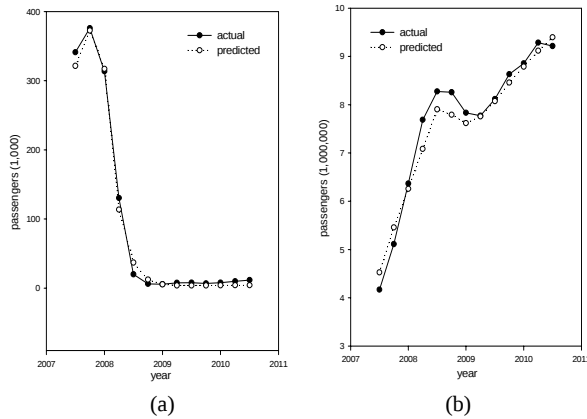


Fig. 4 Actual and predicted passenger volume of (a) domestic civil aviation and (b) THSR by systematic model with oil price.

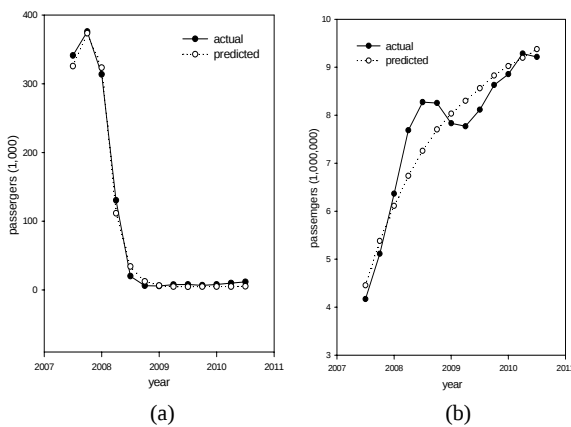


Fig. 5 Actual and predicted passenger volume of (a) domestic civil aviation and (b) THSR by systematic model with GDP per capita.

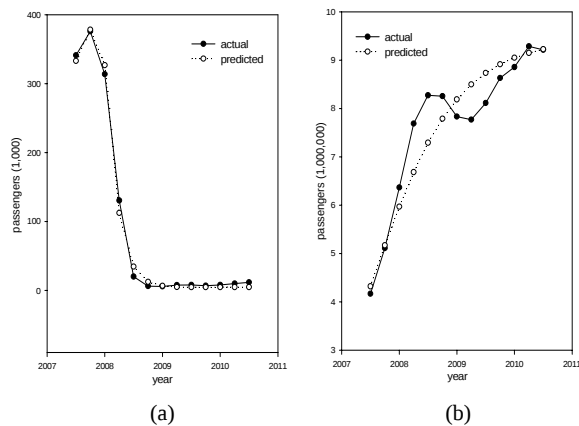


Fig. 6 Actual and predicted passenger volume of (a) domestic civil aviation and (b) THSR by systematic model with CPI.

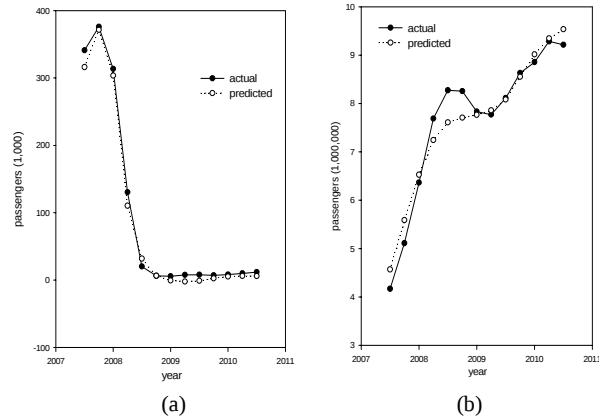


Fig. 7 Actual and predicted passenger volume of (a) domestic civil aviation and (b) THSR by systematic model with economic growth rate.

TABLE II

R-SQUARE VALUE OF PROPOSED EQUATIONS

External variable	Mode	R-square value
Oil price	airline	0.89
	THSR	0.66
GDP per capita	airline	0.89
	THSR	0.28
CPI	airline	0.89
	THSR	0.25
Economic growth rate	airline	0.89
	THSR	0.56

TABLE III

ABSOLUTE PERCENTAGE ERROR VALUE OF PROPOSED MODELS

External variable	Mode	Max (%)	MAPE (%)	Min(%)
Oil price	airline	97.24	39.84	0.89
	THSR	8.63	3.47	0.2
GDP per capita	airline	97.27	34.83	0.65
	THSR	12.34	5.33	0.96
CPI	airline	99.23	35.85	0.65
	THSR	13.06	5.40	0.11
Economic growth rate	airline	128.86	48.42	1.19
	THSR	9.62	3.93	0.37

The values and signs of the coefficients are given in Table IV. According to the coefficients of airline, different external effects do not influence the value of coefficient. Again, the passenger volume of domestic aviation does not influence by social-economic effect significantly. However, the external effects still must be considered in the model. Otherwise, the predicted volume of aviation will have negative value. The coefficients of THSR are influenced by external effects largely and do not have a consistent result.

TABLE IV
COEFFICIENTS OF SYSTEMATIC EQUATIONS

External variable	Mode	a_i	b_i	c_i	d_i
Oil price	Airline	-4.68	9.26×10^{-6}	2.45×10^{-7}	354.21
	THSR	-0.49	2.32×10^{-8}	0	96678.22
GDP per capita	Airline	-4.71	9.3×10^{-6}	2.47×10^{-7}	0.085
	THSR	-0.046	-1.58×10^{-8}	0	7.48
CPI	Airline	-4.70	9.29×10^{-6}	2.47×10^{-7}	36.10
	THSR	0.38	-3.98×10^{-8}	0	-187.06
Economic growth rate	Airline	-4.55	8.95×10^{-6}	2.42×10^{-7}	1133.879
	THSR	0.37	-4.14×10^{-8}	0	38436.79

V.CONCLUSION

In this study, dynamic competitive models with different social-economic variables are compared. According to the results, model with oil price forecasts better than models with GDP per capita, CPI and economic growth rate do. Although the MAPE values do not show significant difference, the results of model with oil price presents the best fitness. Therefore, oil price should be included in dynamic competitive model of transportation systems.

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