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The diversification of railway companies:

Urban land use equilibrium analyses

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Abstract

This study shows the effects of the diversification of railway companies into real estate business on their primary business and the growth of commercial areas along railway lines. Methodologically, a model that combines the urban land use equilibrium model with the optimal train operation problem is formulated and the results of the numerical simulations suggest that the railway company should diversify into real estate in order to expand the retail market whose goods have property of cumulative attractiveness.

Keywords: Diversification of railway companies; Urban land use equilibrium; Agglomeration economies; MPEC

1. Introduction

Private railway companies play an essential role in expanding high-density and productive land use in major Japanese cities. Such diversified companies not only lay rail tracks and run trains but also develop accompanying commercial facilities (e.g., retail and financial businesses, hotels, travel agencies, entertainment venues) and residential areas to meet the needs of the people living along railway lines. Furthermore, they play a considerable role in earning enough profits to secure their futures as private companies without public subsidies, which is rare in the world. Shoji (1993, 2001), by collecting data on the status of major private railway companies in Japan, concludes that their success is based not only on high demand density in Japanese urban areas but also on self-directive management policies and business diversification[1].

In this study, we focus on the diversification of railway companies such as developing commercial facilities along railway lines. To illustrate the participation of private railway companies in the growth in such commercial areas through their diversification into real estate, a standard urban land use equilibrium model is combined with an optimal railway operation problem. Then, the mechanisms that provide synergy effects related to the diversified real estate businesses of railway operations are investigated thorough numerical simulations.

By considering the differentiation of retail goods and diversified business of a railway company, the model proposed herein is extended as an optimization problem of train operations restricted by the urban land use equilibrium model. The structure of the problem, commonly known as an MPEC (mathematical problem with equilibrium constraints) or Stackelberg equilibrium problem, allows us to analyze the effects of adjustments in train operations by railway companies. Two cases—one of a railway company that only operates trains and the other of a company that also runs a real estate business—are analyzed by using comparative statics. Furthermore, to clarify the types of retail businesses that should be targeted by the diversification of railway companies, the cumulative attractiveness of retail shops is evaluated.

2. Literature Review

Anas (1984) integrated the transport network equilibrium model with the urban land use equilibrium model, consistent with urban economics theory. He then applied random utility theory to understand the connection between urban land use and transport choice. Miyagi et al. (1995) reformulated the Lowry-type land use model in accordance with random utility theory, unifying the model as transportation network flows and urban land uses that reach the equilibrium simultaneously. Subsequently, Miyagi and Sawada (2002) analyzed the impacts of different urban transportation strategies on urban land use.

Mun (1995) investigated location patterns and social welfare in land markets of the retail industry by applying a location equilibrium model that takes into account the behavior of standard economic agents such as customers, retailers, developers, and landowners. This study considered the positive externality of the accumulation of retail shops and discrimination by an oligopoly of large-scale

[1] In addition, real estate businesses that build residential properties and commercial facilities contribute heavily to the sustainable growth of railway business by (i) increasing passengers, (ii) fostering cost savings through the effective use of management resources, and (iii) internalizing the development benefits of advance land acquisition.

retail shops. Furthermore, Mun (1997) extended this model, consistent with general equilibrium systems, and investigated the behavior of a system of cities connected by a linear transportation network, including several industries and economies of scale. Finally, Suzuki (2013) analyzed differences in urban land use depending on advanced railway services (e.g., direct services and rapid services) based on Mun's (1995) urban land use equilibrium model and by using numerical simulations. This study found that the change of railway network (e.g., hard infrastructures and soft train operations) differentiates urban land use in various ways.

3. Urban land use equilibrium model of railway lines

3.1 Consumption behavior of residents

We make the following assumptions about the consumption behavior of residents. All residents live along a railway line. They visit the retail shops near local railway stations several times during a given time period. Each resident chooses an area independently for each shopping trip. Their utilities are associated with cumulative attractiveness, expense, time cost, and their place preference. The utility gained by a resident living in area i and shopping at area j is given by

$$V_{ij} = \delta n_j - I - \gamma d_{ij}(t_w) + \varepsilon_{ij} \tag{1}$$

where is the expense during shopping, γ is the value of time, d_{ij} is the travel time, ε_{ij} is the resident's preference for shopping area, and t_w is the time spent waiting on the platform for a train.

Let ε_{ij} be independent and identically distributed. Residents maximize their utility by their choice of shopping area, shown as

$$\max . \sum_{j=1}^{n} V_{ij} \tag{2}$$

Then, the optimal probability that a resident who lives in area i shops at area j is represented by the following logit function:

$$P_{ij} = \frac{\exp \mu\left(\delta n_j - I - \gamma d_{ij}(t_w)\right)}{\sum_{k=1}^{n} \exp \mu\left(\delta n_j - I - \gamma d_{kj}(t_w)\right)} \tag{3}$$

The number of consumers who live in area i and shop at area j is represented by

$$S_{ij} = \alpha_i O_i P_{ij} \tag{4}$$

where O_i is the population in area i and α_i is the consumption frequency.

The consumption frequency denoted in (5) is defined as a decreasing function of the log sum-type cost, where α_0, α_1 are positive parameters:

$$\alpha_i = \alpha_0 + \alpha_1 \frac{1}{\mu} \ln \sum_{j=1}^{n} \exp \mu\left(\delta n_j - I - \gamma d_{ij}(t_w)\right) \tag{5}$$

Finally, the number of consumers who shop at area j is the sum of S_{ij}:

$$D_j = \sum_{i=1}^{n} S_{ij} \tag{6}$$

3.2 Location behavior of retailers

It is assumed that each retailer owns one shop, with a uniform shop size regardless of location. The profit of the retailer operating in area j is expressed by

$$\pi_j = \frac{eD_j}{n_j + 1} - C - ur_j \tag{7}$$

where n_j is the number of retail shops in area j, e is the gross profit for each sale, C is the management cost of each shop, u is the floor space of each shop, and r_j is the rental rate for each unit of floor space.

Latent retailers enter area j only if they expect positive profits. At equilibrium, the following two location patterns come into being:

$$n_j = 0, \quad if \ \pi_j < 0 \tag{8a}$$

$$n_j \geq 0, \quad if \ \pi_j = 0 \tag{8b}$$

3.3 Floor space supply behavior of developers

Assume one developer exists in each area. The developer supplies retail floor space by providing land L_j and capital K_j. The producing technology of retail floor space F_j is given by

$$F_j = K_j^{\tau} L_j^{1-\tau} \tag{9}$$

where τ is a parameter that shows the combination of land and capital in a Cobb–Douglas production function form.

The profit of the developer is formulated as

$$\phi_j = r_j F_j - cK_j - \rho_j L_j + G_j \tag{10}$$

where c is the unit cost of capital, ρ_j is the land rent, and G_j is the revenue related to diversification. This model focuses on the relationships between (i) the increase in passengers and (ii) the cost savings through the effective use of management resources. To simplify the problem, a certain revenue is derived from the real estate business. Then, the propagating mechanism derived from this increase in revenue is observed in the comparative statics. Note that the internalization of development benefit through advance land acquisition is omitted from this study because the models used would have to include the long-term effect to address such a problem.

We assume that developers maximize their profit:

$$\max.\ \phi_j \quad s.t.\ F_j = K_j^{\tau} L_j^{1-\tau} \tag{11}$$

The optimal ratio of capital divided by land is then

$$\frac{K_j}{L_j} = \frac{\tau}{1-\tau}\frac{\rho_j}{c} \tag{12}$$

Demand for retail floor space is equal to supply:

$$un_j = F_j \tag{13}$$

Developers supply retail floor space if they expect positive profits. At equilibrium, we have two supply situations:

$$F_j = 0, \quad if \;\; \phi_j < 0 \tag{14a}$$

$$F_j \geq 0, \quad if \;\; \phi_j = 0 \tag{14b}$$

3.4 Supply behavior of the landowner

Consider that each area has a non-resident landowner who rents land to developers as long as land rents are greater than reservation rents. Let the reservation rent be denoted by b_j. At equilibrium, equations (15a) and (15b) hold:

$$L_j = 0, \quad if \;\; \rho_j < b_j \tag{15a}$$

$$L_j \geq 0, \quad if \;\; \rho_j = b_j \tag{15b}$$

3.5 Numerical calculation method for the model

The above equilibrium conditions can be rewritten as <P1> by using complementarity conditions:

< P1 >

$$D_j = \left(\alpha_0 + \alpha_1 \frac{1}{\mu} \ln \sum_{j=1}^{n} \exp \mu\left(\delta n_j - I - \gamma d_{ij}(t_w)\right) \right) \sum_{i=1}^{n} O_i \frac{\exp \mu\left(\delta n_j - I - \gamma d_{ij}(t_w)\right)}{\sum_{k=1}^{n} \exp \mu\left(\delta n_j - I - \gamma d_{kj}(t_w)\right)} \quad \forall j \in J \tag{16}$$

$$n_j \left(\frac{eD_j}{n_j + 1} - C - ur_j \right) = 0, -\frac{eD_j}{n_j + 1} + C + ur_j \geq 0, n_j \geq 0 \quad \forall j \in J \tag{17}$$

$$\frac{K_j}{L_j} = \frac{\tau}{1-\tau} \frac{\rho_j}{c}, \quad \forall j \in J \tag{18}$$

$$F_j = K_j^{\tau} L_j^{1-\tau}, \quad \forall j \in J \tag{19}$$

$$un_j = F_j, \quad \forall j \in J \tag{20}$$

$$F_j\left(r_j F_j - cK_j - \rho_j L_j + G_j\right) = 0, -r_j F_j + cK_j + \rho_j L_j \geq 0, F_j \geq 0 \quad \forall j \in J \tag{21}$$

$$L_j\left(\rho_j - b_j\right) = 0, -\rho_j + b_j \geq 0, L_j \geq 0 \quad \forall j \in J \tag{22}$$

<P1> is a set of simultaneous equations that includes the parameters $\alpha_0, \alpha_1, O_i, \mu, I, \gamma, d_{ij}$, $e, C, u, \tau, c, b_j, G_j$ and variables $D_j, n_j, r_j, K_j, L_j, F_j, \rho_j$. <P1> has a unique solution because the number of equations corresponds to the number of variables. We calculate the equilibrium location patterns by adopting the Fischer–Burmeister function (Fischer, 1992). The function transforms simultaneous equations, including complementarity conditions, into mathematical optimization problems where τ is a parameter that shows the combination of land and capital in a Cobb–Douglas production function form.

3.6 Optimal operation of the railway company

The railway company sets the frequency of train services to maximize its profit under regulated rail fares. To put it another way, setting the frequency of train services means fixing average waiting time in the station. Therefore, average waiting time is used in place of train service frequency as the instrumental variable of the railway company. Once average waiting time is held, shopping travel volume and its flow pattern (called shopping travel demand below) are fixed and then the income of the railway company is calculated. At the same time, the operation cost of railway services is also calculated in accordance with average waiting time. For the sake of simplicity, a railway company does not invest in infrastructure in the short-term; outgoings are only dependent on the operation cost. It is also assumed that the operation cost is a decreasing function of average waiting time and that the marginal operation cost is negative:

$$\max_{t_w} \Lambda \tag{23}$$

$$\Lambda = \sum_{ij} b_{ij} S_{ij}\left(t_w\right) - Q\left(t_w\right), i \neq j \tag{24}$$

where $S_{ij}\left(t_w\right)$ is the solution of <P1>.

Then, the above profit maximization problem is formulated as a mathematical problem owing to the constraints of the urban land use equilibrium model.

4. Urban land use equilibrium simulations

In this simulation, the features of the railway area are simplified as in the parameter setup to focus on the diversification of the railway company, adjustment of train operations, and property of the goods sold in the retail shops. A monopolistic railway company operates trains on a straight railway line that connects five areas having the same population size; the stations are located in the center of each area and the commercial facilities are located in front of the stations. The retail shops rent space in those facilities. Retail goods are characterized by their price and cumulative attractiveness. Single types of retail goods are sold in all areas. The simulations are examined by changing the parameters of the price and cumulative attractiveness1.

The real estate market is divided by area. Individual developers have a corner of each market but the latent developer enters the market only if it is profitable (i.e., a so-called contestable market). The railway company as the developer enters only area 3, which is located in the center of the railway line. The reservation rents are equal and fixed in all areas.

Residents need a certain amount of time to access the station and retail shops. Thus, if they travel by train, they need time to access the station, waiting time at the station, and travel time. The origin and destination travel times for shopping are presented in Table 1.

The railway company operates all trains at equal intervals and imposes a regulated uniform fare on each. The frequency of trains is adjusted according to shopping travel demand. In other words, the railway company determines average waiting time for passengers to maximize its profits.
First, the effects of urban land use and train operations, which are caused by the difference in the property of the retail goods, are analyzed by comparing cases A1 and B1. Next, the effects of the diversification of the railway company are captured by comparing cases A1 and A2 as well as cases B1 and B2. Finally, the feature of the retail market targeted for entry by a subsidiary real estate business of the railway company is clarified based on the difference between the last two comparisons.

Table 1. Shopping travel times

[2] However, the results are inevitable for the former and thus the results of those simulations are omitted from this article.

O ＼ D	Area 1	Area 2	Area 3	Area 4	Area 5
Area 1	5	$7+t_w$	$9+t_w$	$11+t_w$	$13+t_w$
Area 2	$7+t_w$	5	$7+t_w$	$9+t_w$	$11+t_w$
Area 3	$9+t_w$	$7+t_w$	5	$7+t_w$	$9+t_w$
Area 4	$11+t_w$	$9+t_w$	$7+t_w$	5	$7+t_w$
Area 5	$13+t_w$	$11+t_w$	$9+t_w$	$7+t_w$	5

4.1 Case A1: without cumulative attractiveness and diversification

First, the case in which cumulative attractiveness does not affect shopping behavior and the railway company does not diversify into real estate is investigated as a benchmark for the following comparative statics. From the model formulated in the previous section, the urban land use equilibrium varies according to average waiting time, which is determined by the railway company in expectation of the variation in the urban land use equilibrium. Incomes, outgoings, and profits with respect to waiting times are summarized in Fig. 1. This figure implies that residents reduce their shopping frequency because of the decreased convenience as average waiting time increases. Increasing average waiting time means reducing the number of train services, implying that the outgoings of the railway business fall. Profit increases initially with the increase in average waiting time and then peaks when average waiting time is equal to 4. The optimal average waiting time is thus about 4 in this case.

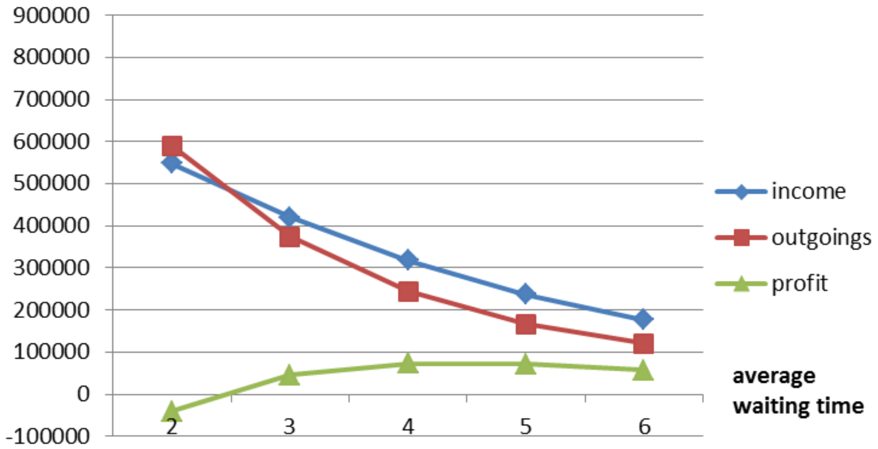

Fig. 1. Operation of the railway company

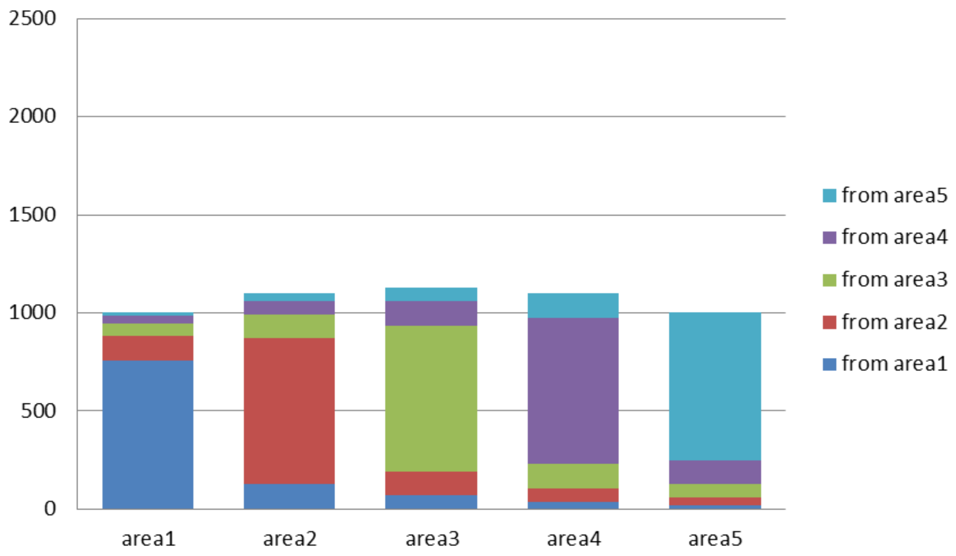

Fig. 2. Breakdown of shopping travel demand in case A1

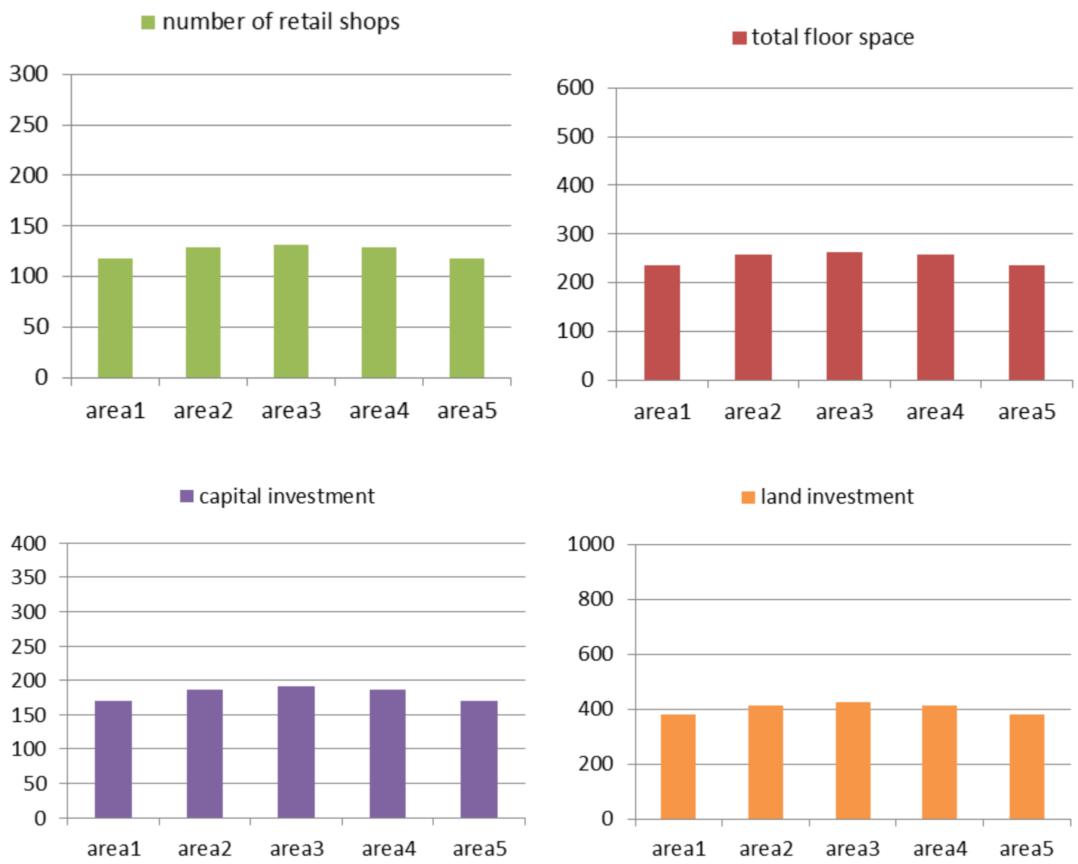

Fig. 3. Urban land use equilibrium in case A1

Next, we observe shopping travel demand and urban land use corresponding to optimal railway operation. Fig. 2 shows the breakdown of shoppers by residential location. The railway connects five areas linearly, the most convenient of which is area 3 followed by areas 2, 4, 1, and 5 in that order. Shopper utility depends on the convenience of shopping travel and preference for shopping area. Cumulative attractiveness does not affect a shopper's utility. The differences in shopping travel demand between areas are relatively minor compared with other cases. The advantage of area 3 is weaker than the disadvantage of areas 1 and 5. The number of retail shops, total floor space, and capital and land investments in each area are determined as a proportionate rate of shopping travel demand, as indicated in Fig. 3.

In terms of the breakdown of shopping travel demand, we see that shoppers mainly choose their shopping destinations based on travel time (naturally, they choose those closest to their living areas more often). Furthermore, rents do not create a large difference in urban land use in this analysis. These are fixed in the numerical simulations since reservation rents and capital costs are fixed in the model.

4.2 Case B1: with cumulative attractiveness but without diversification

Here, the case that cumulative attractiveness affects shopping behavior and the railway company does not diversify into real estate is simulated and compared with case A1. The cumulative attractiveness of shopping for retail goods means that as the number of retail shops increases, the variety of retail goods rises and thus shopper utility improves.

Previously, the urban land equilibrium was compared with that at the same average waiting time (i.e., 4). Shopping travel demand for all areas increases in proportion with the number of retail shops, convenience for shopping travel, and preferences for shopping areas. The share from other areas to areas 2–4 thus expands, as presented in Table 2. These changes are derived from the accumulation of retail shops. Then, shopping travel demand also increases according to the decrease in the share of local shopping.

Additionally, the railway company can optimize train operations as shopping travel demand changes. It increases profits by increasing the frequency of trains; then, it reduces average waiting time to 3 to optimize operations. Table 3 shows that shopping travel demand focuses on areas 2–4. Further, the comparison of Tables 2 and 3 shows that the railway company could decrease the share of shopping in residential areas and then increase shopping in non-residential areas by adjusting train operations.

These results show that the stronger cumulative attractiveness, the greater the increase shopping travel demand, and the higher the number of retail shops, the stronger is the tendency in cumulative areas, meaning that the railway company can increase shopping and train demand to a larger extent by choosing to optimize train operations .

Table 2. Variations in the share of shopping areas by cumulative attractiveness

O ＼ D	Area 1	Area 2	Area 3	Area 4	Area 5	Sum
Area 1	−1.34%	0.66%	0.52%	0.20%	−0.04%	0%
Area 2	−0.68%	0.50%	0.33%	0.05%	−0.20%	0%
Area 3	−0.44%	−0.07%	1.03%	−0.07%	−0.44%	0%
Area 4	−0.20%	0.05%	0.33%	0.50%	−0.68%	0%
Area 5	−0.04%	0.20%	0.52%	0.66%	−1.34%	0%
Average	−0.54%	0.27%	0.55%	0.27%	−0.54%	0%

Table 3. Variations in the share of shopping areas by train optimization

O ＼ D	Area 1	Area 2	Area 3	Area 4	Area 5	Sum
Area 1	−6.95%	3.43%	2.04%	1.03%	0.45%	0%
Area 2	1.91%	−6.58%	2.72%	1.37%	0.58%	0%
Area 3	0.94%	2.25%	−6.37%	2.25%	0.94%	0%
Area 4	0.58%	1.37%	2.72%	−6.58%	1.91%	0%
Area 5	0.45%	1.03%	2.04%	3.43%	−6.95%	0%
Average	−0.62%	0.30%	0.63%	0.30%	−0.62%	0%

4.3 Case A2: without cumulative attractiveness but with diversification

Next, the case in which cumulative attractiveness does not influence shopping behavior and the railway company diversifies into real estate is considered. As described at the beginning of the section, the railway company can increase its supply of floor space in area 3 as a developer to take advantage of the additional revenue arising from diversification. If the railway company only increases floor space when the profit of the subsidiary real estate business is zero, the number of retail shops in area 3 slightly increases but shopping travel demand does not change relative to that in case A1. In this case, the cumulative attractiveness enjoyed by residents is zero and thus travel choices remain fixed.

Consequently, the optimal train operation is held at an average waiting time equal to 4. The railway company ends up spending additional revenue in the real estate market but obtains no additional benefits. If the company is a rational actor, it reserves the additional revenue arising from diversification and supplies floor space in the same manner as the general developer in case A1. Hence, the analysis reveals that the diversification of the railway company into real estate creates only a limited synergetic effect (e.g., a cost saving) when cumulative attractiveness does not influence retail shopping.

4.4 Case B2: with cumulative attractiveness and diversification

Finally, the case in which cumulative attractiveness affects shoppers and the railway company diversifies into real estate is examined. The railway company also increases the supply of floor space in area 3 as a developer. In contrast to case A2, residents go shopping more often relative to case B1, especially to area 3 (Fig. 4). The increase in shopping demand makes the diversified railway company supply more floor space. As a result, shopping travel demand increases and area 3 steals shopping demand from other areas both in absolute number and in market share. As seen in Fig. 5, the effects of diversification are generally concentrated on the retail shops in area 3.

Since the additional revenue from diversification is relatively small, it does not change the optimal train operations of the railway company; hence, the synergetic effects are intensified between train operations and urban land use. However, the diversification of the railway company into real estate increases profit for the railway business. Indeed, even if the additional revenue is funded by the interdivisional transfer from the railway sector to the real estate one, total profit rises across the company. Therefore, the analysis suggests a strong incentive for the railway company to diversify into real estate when cumulative attractiveness influences retail shopping.

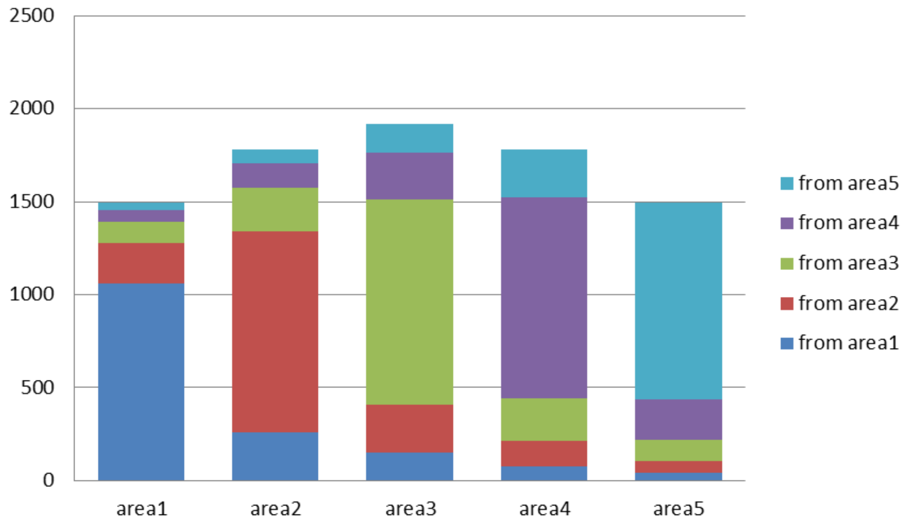

Fig. 4. Breakdown of shopping travel demand in case B2

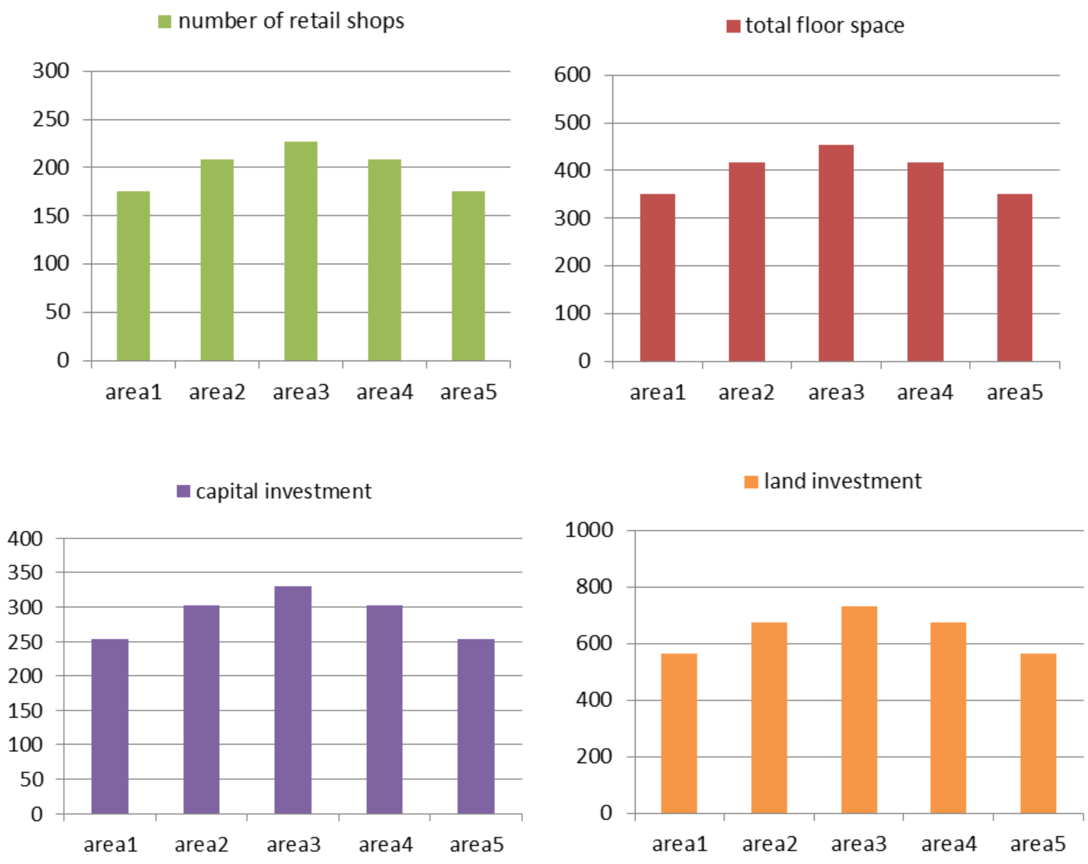

Fig. 5. Urban land use equilibrium in case B2

5. Conclusions

The present study shows the effects of the diversification of railway companies into real estate business on their primary business and the growth of commercial areas along railway lines. Methodologically, a model that combines the urban land use equilibrium model with the optimal train operation problem is formulated and the results of the numerical simulations suggest that the railway company should diversify into real estate in order to expand the retail market (whose goods have the property of cumulative attractiveness).

We can explain these findings as follows. First, the change in urban land use provides the railway company with an opportunity to improve train operations in accordance with variations in passenger flow. Second, the railway company has an exclusive tool for generating profit from the increase in shoppers, which allows it to develop more commercial facilities compared with general developers. Third, expanding the consumption of goods (i.e., through cumulative attractiveness) increases the profit of the railway company, not only directly, such as the increase in shopping frequency, but also indirectly, such as the differentiation of station areas with the change in urban land use. Fourth, the diversified real estate business of the railway company may improve the welfare of residents living along railway lines because the effects spread through the increase in passenger convenience.

Japanese private railway companies have long successfully diversified into new markets, contributing to a growth in living standards in urban areas through the development of commercial facilities and opening of retail stores. The findings presented in this paper are thus consistent with the recent trend for the redevelopment of main stations. Therefore, the effectiveness of these redevelopments holds the key to growth in urban areas of Japan.

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