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# Empirical Analysis for Impact of High-Speed Rail Construction on Interregional Dependency

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**Abstract:** The opening of the high-speed rail (HSR) resulted in significant changes in the transportation network of Korea. The new HSR construction was expected to become a new engine of local economic growth. However, there was a controversy regarding whether the connection between regions intensifies the concentration of socio-economic activities in the metropolis (straw effect) or contributes to the balance of regional development (sprawl effect). More increasing attention had been devoted to studying the “straw effects” caused by the newly built HSR networks on interregional social-economic activities. Despite considerable research on the benefit achieved from HSR construction, little has focused on the negative externalities resulting from it. This paper examined the potential “straw effects” of two new HSR lines through constructing the indicator of interregional dependency that measured one city’s level of dependency on another one. In order to exclude the interference of lurking variables, five metropolitan cities were selected as case studies. The empirical results, based on a panel data model, revealed that the larger the economic scale of the target city, the lower the level of dependency on other cities, and there existed a “straw effect” on HSR development in terms of Seoul.

**Keywords:** market accessibility; straw effect; lurking variable; panel data model; interregional dependency

## 1. Introduction

High-speed rail (HSR) has been introduced and planned in many countries over the last fifty years since the first HSR line (Shinkansen line in Japan) operated in 1964. Following Japan, more and more countries started to provide a HSR service, such as France, Germany, Spain, Italy, Korea, and China [1]. Korea operated the Korea Train Express (KTX) services of the Gyeongbu HSR Line in 2004. The operation of the KTX resulted in significant changes in the transportation network of Korea, which changed the entire country from a “one-day life zone” into a “half-day life zone”, that reduced the travel time within Korea to less than 3 h [2]. This change has exerted profound influences on the local society, economy, and culture of each district in Korea. On the one hand, the development of HSR contributes to maintaining close economic relations between different areas. This would strengthen the cooperation between upstream and downstream enterprises and then lead to the decrease in the cost of them, while at the same time more jobs will be created with the expansion of production and market [2–4]. On the other hand, the outstanding performance of high-speed transport modes in increasing the volume and speed of interregional migration contributes to improving the efficiency of domestic trades and creating new economic growth points, such as new commercial areas based on new high-speed railway stations [5–7]. In addition, the HSR was also conducive to improving the efficiency of land use, technological innovation, and trade liberalization in Korea [2].

However, some researchers raise concerns about the local economic growth of socioeconomically disadvantaged areas, as they may face the adverse shocks resulting from the operation of HSR, that is the so-called “straw effect”, which refers to the relative concentration of economic resources in a developed city at the expense of weakening the economic vitality of neighboring smaller cities [8,9], just like juice in a glass is sucked up by a straw [8]. The theory behind this effect can be traced to the growth pole theory, which was developed by Francois Perroux (1950), who emphasized that the existence of growth poles would lead to the imbalance of regional development [10]. In this connection, some researchers developed this theory from different perspectives, such as Hirschman (1958), who proposed the trickling down effect, which referred to the positive impact of a growth pole or growth center on adjacent regions [11]. Myrdal (1957) used the terms “spillover effect” and “backwash effect” to describe the relationship between core areas and the periphery [12]. Prebisch (1950) systematically summarizes the center-periphery theory that was introduced into the regional economic analysis by Friedman (1966) [13]. He found that the ongoing economic and political success of one region or state may be achieved at the expense of neighboring areas [14]. With the development of the New Economic Geography (NEG) theory, Krugman (1991) constructed a core-periphery model from the perspective of spatial economics, who emphasized the role of transportation cost in forming a core-periphery structure [15].

In terms of empirical research on the straw effect, most of them have inferred that investment in public transport infrastructure would have a strong and positive effect on regional economic development through reducing travel costs and increased interregional economic activity [16–18]. Some early works on the U.S. and Europe found the positive effects of new transport infrastructures on local economic productivity and narrowing the gaps between core cities and other cities [1,19,20]. At the same time, the positive effects may not be consistent, and the straw effects tend to result in an uneven distribution of benefit from a new high-speed railway construction for different cities [21–23]. Some previous research on Japanese high-speed railway confirmed the “straw effects” in the mid-1990s [9], which consequently resulted in small cities gradually becoming an appendage of major cities and the dramatic decrease in employment, particularly service industries, without positive spillover effects.

Regarding Korea, coupled with the operation of high-speed transport, many studies have found these adverse effects. Kim (1994) found that, with the operation of a new highway, customers of a major department store in the regional city experienced a decrease, due to the higher accessibility of superior shopping malls in Seoul [24]. In recent studies, some researchers attempted to measure a straw effect by increasing daytime travelers in the Seoul area with the opening of KTX, and found that major cities get more marginal benefits than local towns [25–27]. However, some other studies also argued that there is little evidence of the straw effect in Korea. The study showed that the growth rate of the population in Seoul Metropolitan Areas before KTX was 16.1% from 1999 to 2003, but the rate dropped to 12.5% after KTX opened, from 2004 to 2007 [28]. Therefore, there are still no conclusive results on the socio-economic impacts of newly built transport systems. The straw effects of new HSRs may result in an unbalanced economic landscape and higher local dependency on significant cities [1]. Moreover, in Korea, there are still some controversies on whether or not the local human resources are concentrated in the metropolitan areas due to the new HSR construction [1,29]. Kim et al. (2010) found that the KTX construction would alleviate the excessive agglomeration of the population and employment in Seoul city [30]. Similarly, Kim and Han (2016) found that the KTX construction stimulated the increase in population and industry in lagging areas, as well as local highway accessibility without the straw effects [31].

In general, little research has paid attention to the negative externalities of the new HSR network [31], especially the straw effect. This paper will examine the straw effect by a case study on the operation of KTX in Korea. In order to analyze the change in interregional social-economic activity patterns after the KTX opening, we introduced the concept of interregional economic dependency, based on the center-periphery theory proposed by Prebisch (1950), which distinguishes the role in

global economic development that countries in the core has played from those who are not [14]. Peripheral countries will, to a large extent, depend on core countries to get manufactured goods and the consumption of services. Similarly, this theory can also be applied to cities within a country to show their different transport positions. As the traffic volume between two cities can, to some degree, reflect the degree of connection between them, we used it to represent the strength of city's attachment to the city's interest. Therefore, the more traffic volume flow in the city  $i$  from the city  $j$ , the more dependent city  $j$  becomes on city  $i$ . In previous studies, economic dependency was measured by the number of floating populations, such as commuting traffic [32–34]. However, in most studies, the quantification of dependency is limited by the measure of commuting traffic, so this study uses interregional travel OD (Origin and Destination) data to deal with this problem from the perspective of economic dependency.

The purpose of this paper was to examine if there exists a straw effect resulting from two new HSRs in Korea. This study makes the following contributions to the literature: First, we examine the straw effect from the perspective of economic dependency derived from the center-periphery theory. Second, we construct a panel data model that includes variables, such as traffic volume by each city of interest and city characteristic variables, to conduct the empirical analysis of the impacts of the new HSR. Third, this study chooses the market access that combines economic variables with traffic data as the alternative key variable to do the robustness test, which suggests the consistency of our results.

## 2. Study Assumptions and Study Area

### 2.1. Study Assumptions

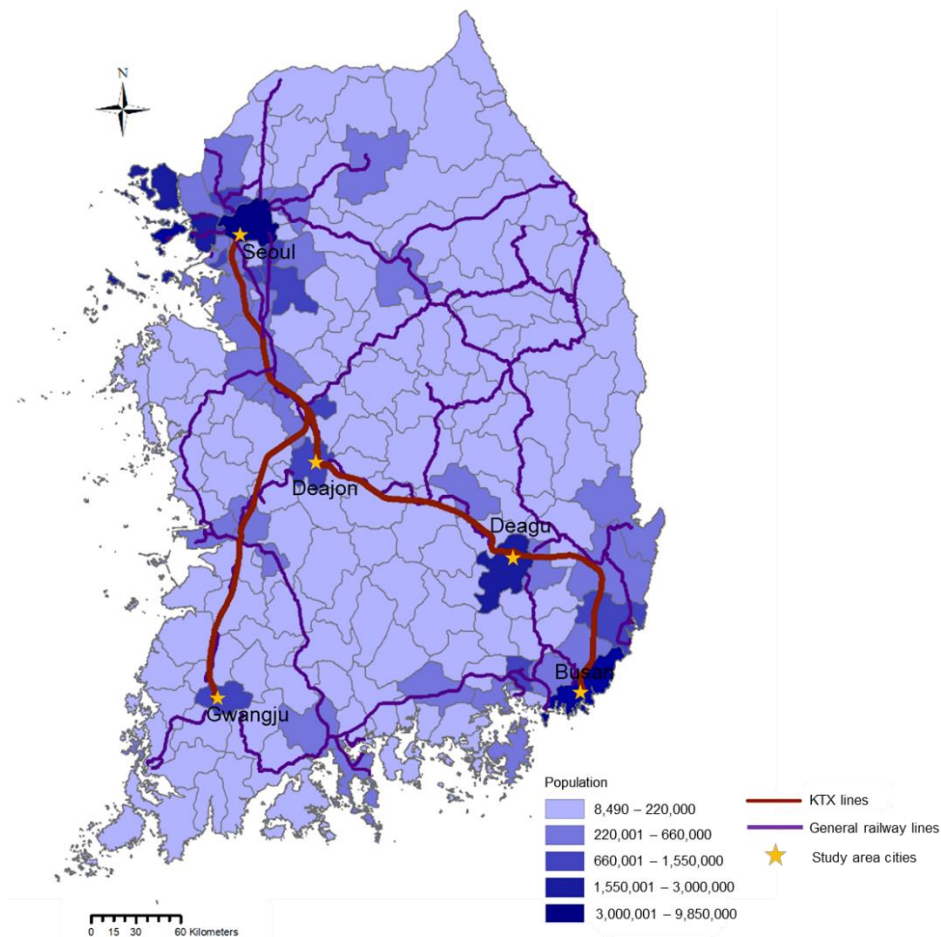
This paper aimed to examine the impact of the new KTX operation on interregional dependency. However, the regional socio-economic changes caused by KTX are not spatially distributed evenly, which extends outside of KTX stations. Thus, cities with KTX stations are selected as a case study in this research. Besides, there are many other factors affecting urban socio-economic activities, such as human resources, technology, government expenditures, etc., during KTX operation. In order to omit the disturbance of lurking variables, we further chose cities with little difference in urban scale as the research targets. Because of these restrictions, this study proposes three assumptions before empirical analysis:

- First, interregional socio-economic dependency, as with the need for job opportunities, cultural activities, leisure services, education, and commercial communication, to a certain extent, can be represented by the interregional traffic volume. That is to say, the interregional traffic reflects people's demand for infrastructure and the scale of the local economy.
- Second, as Korea has formed a well-developed transportation infrastructure before the construction of KTX, we assume that all traffic facilities, except the KTX, are consistent during the study period.
- Third, there is no significant difference in the rate of socio-economic scale change among cities involved in this study.

### 2.2. Study Area

Consistent with the underlying assumptions above, the cities of interest are all located in economically developed areas along the KTX lines, because: (a) there was not much change in the traffic facilities (e.g., highway), except for KTX development, during the research period, which means that the construction of infrastructures is relatively completed in these areas; (b) the gap among these areas was not too large in terms of infrastructure development and the rate of socio-economic scale change. Consequently, five metropolises (i.e., Seoul, Busan, Daegu, Daejeon and Gwangju) in Korea, along with the two newly built KTX lines—the Gyeongbu Line (Seoul to Busan) and Honam Line (Seoul to Gwangju)—were chosen as the target. These five cities account for 36% of the country's population and 34% of its GDP. Especially, Seoul is the capital of Korea, which is the center of industry, finance, trade, science, culture, and education in the country.

The KTX Gyeongbu Line from Seoul to Daegu, with the maximum operating speed at 300 km/h, was completed in 2004 as part of the first stage of the Korean HSR network. The travel time between Seoul and Busan was, therefore, reduced from 4 h and 10 min to 2 h and 40 min. In November 2010, the operation of the Daegu–Busan line as part of the second stage of the HSR network further shortened the travel time from Seoul to Busan by about 44 min. In 2015, the Honam KTX line (Seoul to Gwangju) was completed, the time of Seoul to Gwangju being reduced from 2 h and 39 min to 1 h and 33 min, which would generate more travel demand. The regional distribution is illustrated in Figure 1.



**Figure 1.** Study area. Notes: Data source comes from Korea Transport Database (<https://www.ktddb.go.kr/eng/index.do>).

### 3. Data and Methods

#### 3.1. Data Source

In order to estimate the interregional dependency, we constructed a panel data model based on the data from five Korean metropolitan cities (Seoul, Busan, Deagu, Dejon, and Gwangju) observed between 2001 and 2017. The data released pertain to KTX GIS data ends in 2017 and the rapid development of transportation construction in the 2000s; therefore, we chose this period.

The dependent variable used in the study is interregional dependency ( $RD_{ijt}$ ), which measures to what degree city  $i$  depends on city  $j$  in terms of social and economic activities in year  $t$ . Given previous studies, we calculated it based on the interregional trips data from the website of the Korea Transport Database (KTDB). This database includes the operation of transport infrastructure, origin–destination

(O/D) travel, traffic attributes, and transport networks, which is an official and reliable data source on the topic of Korean transportation. The specific equation can be written as follows:

$$RD_{ijt} = (T_{ijt}/T_{i* t}) / (T_{*jt}/T_{**t}) \tag{1}$$

where  $T_{ijt}$  is the traffic volume from city  $i$  to city  $j$  in year  $t$ ,  $T_{i* t}$  indicates the total outflow volume of city  $i$  in year  $t$ ,  $T_{*jt}$  represents the total inflow volume of city  $j$ , and  $T_{**t}$  represents the total interregional trips across the country in year  $t$ . Table 1 reports a summary of interregional travel inflow and outflow with the example of Busan.

**Table 1.** An example of interregional trip origin–destination (O/D) data.

|                 | Seoul    | Busan | Daegu    | Gwangju  | Daejeon  | $\sum_i T_{ij}$ |
|-----------------|----------|-------|----------|----------|----------|-----------------|
| Seoul           | 0        | ...   | ...      | ...      | ...      | ...             |
| Busan           | $T_{bs}$ | 0     | $T_{bd}$ | $T_{bg}$ | $T_{bd}$ | $T_{b*}$        |
| Deagu           | $T_{ds}$ | ...   | 0        | ...      | ...      | ...             |
| Gwangju         | $T_{gs}$ | ...   | ...      | 0        | ...      | ...             |
| Daejeon         | $T_{ds}$ | ...   | ...      | ...      | 0        | ...             |
| $\sum_j T_{ij}$ | $T_{*s}$ | ...   | ...      | ...      | ...      | $T_{**}$        |

Note:  $T_{bs}$ ,  $T_{bd}$ ,  $T_{bg}$ ,  $T_{bd}$  are the O/D trips from Busan to Seoul, Deagu, Gwangju, and Daejeon.  $T_{b*}$ ,  $T_{*s}$ , and  $T_{**}$  denote total trips from Busan, total inflow traffic to Seoul, and total O/D trips, respectively.

Authors should discuss the results and how they can be interpreted from the perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

In order to examine the impact before and after the opening of KTX, we used the dummy value ( $ktx1$ ), which shows the situation of interregional KTX connection (1, connected; 0, unconnected) as our key explanatory variable. We also collected the city characteristic variables, including the proportion of economically active population ( $ecopopr$ ), the number of enterprises per capita ( $enterm$ ), the ratio of university students ( $univer$ ), green area ( $gland$ ), number of higher education teachers per 10,000 population ( $teachp$ ), price index with the base year 2005 ( $cpi$ ), number of beds in health care institutions ( $bed$ ), and the number of travel enterprises ( $travel$ )—some of them are all logarithmically transformed in order to avoid non-normality and heteroscedasticity. These city characteristic variables are all obtained from the website of the Korea Statistical Office (KOSIS). The specific descriptive statistics of involving variables in this study can be found in Table 2.

**Table 2.** Descriptive statistics of main variables.

| Variable     | Obs. | Mean    | Std. Dev. | Min    | Max     |
|--------------|------|---------|-----------|--------|---------|
| $RD$         | 340  | 1.2269  | 0.6482    | 0.1724 | 2.5499  |
| $ktx1$       | 340  | 0.7647  | 0.4248    | 0      | 1       |
| $lnecopopr$  | 340  | 1.7972  | 2.2399    | 0.2442 | 9.0465  |
| $enterm$     | 340  | 3.8919  | 0.0501    | 3.7861 | 4.0026  |
| $lnuniver$   | 340  | 0.0656  | 0.0135    | 0.0354 | 0.0835  |
| $lngland$    | 340  | 1.5473  | 0.3411    | 0.8311 | 2.0307  |
| $ln teachp$  | 340  | 6.0266  | 0.3336    | 5.4570 | 6.6495  |
| $ln cpi$     | 340  | 2.5331  | 0.4217    | 1.6240 | 3.2625  |
| $ln bed$     | 340  | 4.4688  | 0.1274    | 4.2237 | 4.6367  |
| $ln dtravel$ | 340  | 10.2548 | 0.6301    | 9.1152 | 11.4231 |

Notes: Data source come from Korea Transport Database (<https://www.ktdb.go.kr/eng/index.do>).

3.2. Methods

The purpose of this study was to examine the possible effects of HSR on the interregional flow of population and industrial restructuring. The specific mechanism can be found in Figure 2.

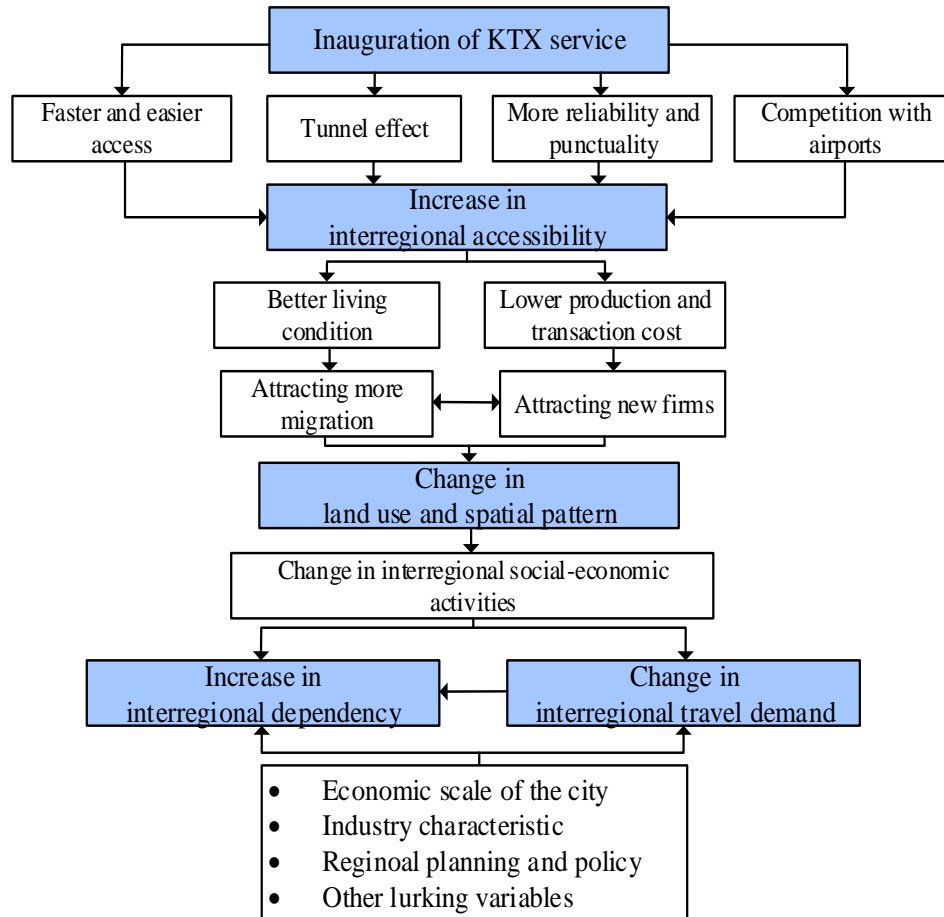


Figure 2. Mechanism of how the KTX (Korea Train Express) construction affected interregional dependency.

We think that both city scale and the construction of HSR are essential to the dependency of a specific city upon another one. As the cross-section data only consider city characteristic variables and the time series data only reflect the development of HSR, the panel data integrate time-series dynamics with the cross-sectional shapes, which allow us to examine the effect of HSR on dependency from both perspectives at the same time. In view of the general form of the panel data model, we constructed the following model to deal with the empirical analysis in this study:

$$RD_{ijt} = \alpha_0 + \beta_0 ktx_{it} + \sum \beta_1 X_{it} + \delta_i + \rho_t + \varphi_{it} \tag{2}$$

where  $RD_{ijt}$  indicates the dependency of city  $i$  upon city  $j$  in year  $t$ .  $ktx_{it}$  is a dummy variable that represents the connection of city  $i$  to the HSR network in year  $t$  (1, connected; 0, not connected).  $X_{it}$  is a set of city characteristic control variables, and  $\alpha_0$  is the intercept, which is independent of  $i$  and  $t$ .  $\delta_i$  represents the time constant unobserved heterogeneity,  $\rho_t$  is the time dummy to control affecting factors that vary with time.  $\varphi_{it}$  denotes the error term, varies over  $i$  and  $t$ .

There are two forms of panel data model: the fixed effect model and random effect model. The former assumes that the individual effect is constant within a group, the intercept varies over individuals, the latter assumes that the intercept is constant over individuals and inter-individual variability is random. The suitable form of the model depends on the results of the Hausman test.

With respect to this study, the results of the Hausman test show that the fixed effect model is more suitable here (the specific results are not shown due to the limited space, but are available upon request).

#### 4. Analysis and Results

Before the empirical analysis, we examined the correlation between variables to address the concern of multicollinearity. The results are reported in Table 3.

**Table 3.** Correlation coefficient matrix.

| Variable: | RD    | ktx1  | Lnecopopr | Enterm | Lnuniver | Lngrand | Lnteachp | Lncpi | Lnbed | Lndtravel |
|-----------|-------|-------|-----------|--------|----------|---------|----------|-------|-------|-----------|
| RD        | 1.00  |       |           |        |          |         |          |       |       |           |
| ktx1      | 0.01  | 1.00  |           |        |          |         |          |       |       |           |
| lnecopopr | 0.14  | 0.52  | 1.00      |        |          |         |          |       |       |           |
| enterm    | 0.27  | 0.16  | 0.29      | 1.00   |          |         |          |       |       |           |
| lnuniver  | 0.21  | 0.15  | 0.02      | 0.83   | 1.00     |         |          |       |       |           |
| lngrand   | -0.42 | -0.13 | -0.49     | -0.68  | -0.46    | 1.00    |          |       |       |           |
| lnteachp  | 0.11  | 0.15  | 0.29      | 0.67   | 0.78     | -0.53   | 1.00     |       |       |           |
| lncpi     | -0.02 | 0.57  | 0.65      | 0.26   | 0.20     | -0.13   | 0.34     | 1.00  |       |           |
| lnbed     | 0.04  | 0.37  | 0.76      | 0.34   | -0.08    | -0.51   | 0.24     | 0.43  | 1.00  |           |
| lndtravel | 0.26  | 0.12  | 0.02      | 0.01   | 0.09     | 0.09    | -0.06    | 0.17  | -0.20 | 1.00      |

The correlation coefficient matrix shows that most correlation coefficients are less than 0.5; thus, there is no severe multicollinearity problem. The estimates of Equation (2) are reported in Table 4.

**Table 4.** Baseline results.

|                | (1)                     | (2)                     | (3)                    | (4)                   | (5)                     |
|----------------|-------------------------|-------------------------|------------------------|-----------------------|-------------------------|
| Models         | Model 1                 | Model 2                 | Model 3                | Model 4               | Model 5                 |
| ktx1           | 0.2487 *<br>(0.0914)    | 0.0051<br>(0.0979)      | -0.0927<br>(0.2408)    | -0.0544<br>(0.5041)   | 0.1724<br>(0.0782)      |
| lnecopopr      | -3.3319<br>(2.7746)     | -2.1424<br>(2.1886)     | 1.5325<br>(2.1513)     | 0.1495<br>(1.5743)    | 0.2227<br>(1.5489)      |
| enterm         | 79.5926 ***<br>(8.4704) | -19.5364<br>(20.4470)   | -105.1740<br>(57.2592) | 16.7092<br>(24.3095)  | 79.8439 **<br>(18.1215) |
| lnuniver       | -0.3994<br>(1.0236)     | 0.7043<br>(0.9877)      | 1.4213<br>(1.1881)     | -0.5460<br>(0.4407)   | -1.1135<br>(1.1551)     |
| lngrand        | 0.4914<br>(0.3697)      | 0.9390<br>(0.4091)      | 0.1488<br>(0.3500)     | -1.3867<br>(0.7822)   | -0.3034 **<br>(0.0677)  |
| lnteachp       | -0.1161<br>(0.4358)     | 0.0821<br>(0.4213)      | -0.1019<br>(0.6616)    | 0.7205<br>(0.4893)    | 1.0843 *<br>(0.4220)    |
| lncpi          | 1.7040<br>(0.9729)      | -11.1162<br>(6.7491)    | -0.3138<br>(0.9319)    | -1.5278<br>(0.8912)   | -3.3882<br>(12.2789)    |
| lnbed          | -0.5951 **<br>(0.1103)  | 0.2715<br>(0.2129)      | 0.4862<br>(0.2344)     | 0.8623 **<br>(0.2340) | -0.0313<br>(0.1100)     |
| lndtravel      | -0.8399<br>(0.6030)     | 46.1717<br>(32.1931)    | 0.9922<br>(0.6256)     | -0.7073<br>(0.4695)   | -0.0375<br>(7.0598)     |
| Constant       | 12.4904<br>(9.9992)     | -239.3733<br>(159.5139) | -9.9969<br>(13.7150)   | 8.8060<br>(12.3647)   | 11.0173<br>(9.9305)     |
| Time control   | Yes                     | Yes                     | Yes                    | Yes                   | Yes                     |
| City control   | Yes                     | Yes                     | Yes                    | Yes                   | Yes                     |
| Observations   | 68                      | 68                      | 68                     | 68                    | 68                      |
| R <sup>2</sup> | 0.5091                  | 0.5290                  | 0.4514                 | 0.5660                | 0.4334                  |

Notes: Robust standard errors in parentheses, \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ .

As shown in Table 4, we estimate whether or not the straw effect exists after the operation of KTX, based on a panel data model. Columns (1)–(5) report the change in relative attraction of Seoul, Busan, Daegu, Gwangju, and Deajon before and after the operation of KTX. All regressions include city and time-fixed effects. We found that the coefficient of *ktx1* was significantly positive in the situation of

Seoul, which suggests that the relative attraction of Seoul increased after the operation of KTX, while this effect was not significant or even negative in terms of the other four cities. As with the abovementioned hypotheses, the interregional traffic volume, to a large extent, reflects the interregional socio-economic dependency, the positive relationship between the operation of KTX, and the dependency of other cities upon Seoul suggests that their urban functions may be absorbed to Seoul through the accumulation effect in the long run—that is, the potential straw effect would prevail over time. This finding is also consistent with Kim (2011), who found that the construction of a highway network might lead to an asymmetric effect on local economic growth across cities in Korea, especially socioeconomically advantaged areas benefitting more from this improvement than those relatively lagging areas [35]. Therefore, we can imply that Seoul could take advantage of the position of central city in terms of economics and culture to achieve utility differentials derived from these advantages after the KTX construction—besides these advantages may become increasingly significant over time due to the accumulation effect. In contrast, the local population and associated economic activities in a relatively developing area would potentially decrease as individuals put more emphasis on the accessibility to employment when choosing household location [36], then the straw effects occur. The results underscore the importance of making a comprehensive assessment on the costs and benefits of new HSR planning, particularly the regional disparity in terms of socioeconomic development.

As HSR development exerts influence on resource allocation through improving the accessibility of cities that connect to the new transport network, accessibility has been an essential means to assess the potential accessible resources reached by transport within a certain distance [37–39]. Donaldson and Hornbeck (2016) introduced market access into their research to reflect the changes in accessibility so as to examine the role that railway construction had played in American economic growth [7]. Moreover, the attractiveness of potential destinations (e.g., employment, gross domestic product (GDP)) and the cost of reaching the destinations (e.g., travel time, generalized travel cost) are usually considered together when calculating the accessibility [40]. Market access is capable of quantifying the overall impact of railway development, which provides a reference for us in analyzing the effect of KTX on the relative attraction of cities in Korea.

We construct market access as below:

$$MA_o = \sum_{d=1}^n c_{od}^{-\theta} P_d \quad (3)$$

where  $MA_o$  denotes the market access of city  $o$ ,  $c_{od}$  denotes the minimum commuting time from city  $o$  to city  $d$ ,  $\theta$  represents the elasticity of trade,  $P_d$  represents the market size of city  $d$  (GDP in this paper), and  $n$  denotes the number of cities.

We used market access, calculated through ArcGIS 10.2, as the alternative independent variable to check the robustness of our main results. The improved accessibility of different geographic areas caused by new HSR constructions contributes to the exchanges of personal and information among them, particularly between areas that have been connected to the HSR network together. So, the changes in market access, attributable to new HSR constructions of a city, could function as an indicator to measure the level of HSR development. However, with the development of KTX, the market access of each city will be improved to a different degree, major cities may benefit more from it as their economic and cultural status enables them with more decision-making power over the planning and construction of new transport infrastructures, then acquiring a comparative advantage in the competition of attracting people. The results with market access as the key independent variable are shown in Table 5—across columns we find a similar pattern of coefficients, which provide additional support for our baseline results.



**Table 5.** Results with market access.

|                | (1)                     | (2)                     | (3)                   | (4)                    | (5)                       |
|----------------|-------------------------|-------------------------|-----------------------|------------------------|---------------------------|
| Models         | Model 1                 | Model 2                 | Model 3               | Model 4                | Model 5                   |
| ma1x           | 0.7245 *<br>(0.2284)    | −0.0101<br>(0.0536)     | −0.0679<br>(0.0292)   | −0.0877 **<br>(0.0259) | −0.1451 ***<br>(0.0227)   |
| lnecopopr      | −2.2998<br>(2.4783)     | −2.1903<br>(2.3531)     | 0.4580<br>(1.1651)    | −1.0725<br>(1.7767)    | 0.7993<br>(1.1750)        |
| enterm         | 56.6395 ***<br>(5.2681) | −17.0541<br>(34.3528)   | −91.1038<br>(47.7476) | 16.7524<br>(20.9843)   | 105.5330 ***<br>(10.2972) |
| lnuniver       | −0.6220<br>(1.0777)     | 0.5729<br>(1.3678)      | 1.4035<br>(1.3002)    | −0.6414<br>(0.4403)    | −1.6614<br>(0.8283)       |
| lngland        | 0.7063 *<br>(0.2788)    | 0.9561 *<br>(0.3210)    | 0.0891<br>(0.1883)    | −0.9684<br>(0.4658)    | −0.1415 *<br>(0.0465)     |
| lnreachp       | −0.0171<br>(0.4140)     | 0.1074<br>(0.4618)      | −0.3890<br>(0.5641)   | 0.7213*<br>(0.2902)    | 1.2206 ***<br>(0.1098)    |
| lnpci          | 1.2202<br>(0.7605)      | −10.6831<br>(7.0185)    | 0.9688<br>(1.3824)    | −1.1942<br>(0.5079)    | 0.2521<br>(4.7883)        |
| lnbed          | −0.1988<br>(0.1017)     | 0.2413<br>(0.2755)      | 0.1739<br>(0.1689)    | 0.4128<br>(0.1896)     | −0.6191 ***<br>(0.1008)   |
| lntravel       | −0.9590<br>(0.4829)     | 44.8464<br>(33.3957)    | 0.9061*<br>(0.2859)   | 0.0036<br>(0.4390)     | −1.1955<br>(2.4965)       |
| Time control   | Y                       | Y                       | Y                     | Y                      | Y                         |
| City control   | Y                       | Y                       | Y                     | Y                      | Y                         |
| Constant       | 7.5511<br>(10.2808)     | −232.5805<br>(169.2619) | −7.6162<br>(8.5216)   | 10.2069<br>(7.0936)    | 3.8688<br>(3.2043)        |
| Observations   | 68                      | 68                      | 68                    | 68                     | 68                        |
| R <sup>2</sup> | 0.4829                  | 0.5294                  | 0.4586                | 0.6085                 | 0.4705                    |

Notes: Robust standard errors in parentheses, \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ . We set the  $\theta$  as 1 and GDP as the market size.

Column (1) in Table 5 shows that a one unit increase in the market access of Seoul is associated with a 0.7 unit increase in the dependency of other cities on it, while columns (2) to (5) suggest that improved accessibility would reduce the attraction of each non-Seoul city, and this effect is more substantial for Deajon and Gwangju. This finding is consistent with our expectation that socioeconomically disadvantaged areas would lose more urban functions with the improvement of accessibility relative to developed areas.

In addition, as the change of  $\theta$  could induce the change in market access, and the market size can be represented by GDP or population. For the consideration of robustness, we further choose different values of  $\theta$  accompanied by GDP and population as the market size, respectively, according to the research of Lin (2017) [41] and Hornbeck and Rotemberg (2019) [42]. Specifically, we constructed another five market access indicators as *ma2x* (1, population), *ma3x* (2.75, population), *ma4x* (2.75, GDP), *ma5x* (3.6, population), and *ma6x* (3.6, GDP). The former value in parentheses denotes different  $\theta$ —the latter indicates different sets of market size. We re-estimated Equation (2) with these alternative independent variables and the results, reported in Table 6, suggest that our main findings are robust to these alternative calculations as well.

**Table 6.** Additional robustness test.

|        | (1)                    | (2)                 | (3)                 | (4)                   | (5)                     |
|--------|------------------------|---------------------|---------------------|-----------------------|-------------------------|
| Models | Model 1                | Model 2             | Model 3             | Model 4               | Model 5                 |
| ma2x   | 24.6666 **<br>(5.5449) | −0.1102<br>(1.6010) | −3.6657<br>(2.5841) | −4.5840<br>(1.9957)   | −4.4747 **<br>(1.3032)  |
| ma3x   | 0.0295 *<br>(0.0097)   | −0.0005<br>(0.0021) | −0.0043<br>(0.0028) | −0.0042<br>(0.0022)   | −0.0061 ***<br>(0.0010) |
| ma4x   | 14.2537 *<br>(4.6376)  | −0.2065<br>(0.8448) | −0.9629<br>(0.5260) | −0.9985 *<br>(0.4090) | −2.0066 ***<br>(0.2180) |
| ma5x   | 0.8242 *<br>(0.2932)   | −0.0166<br>(0.0646) | −0.1214<br>(0.0751) | −0.1074<br>(0.0612)   | −0.1789 ***<br>(0.0300) |
| ma6x   | 0.0419 *<br>(0.0147)   | −0.0006<br>(0.0026) | −0.0027<br>(0.0016) | −0.0026<br>(0.0012)   | −0.0059 ***<br>(0.0007) |

Notes: Robust standard errors in parentheses, \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ . The control variables are the same as in Tables 4 and 5, which are not reported here due to limited space.

## 5. Discussion and Conclusions

In recent years, research on the effect of KTX on urban development has paid more attention to population mobility, regional economic development, and the imbalance of regional development. However, little has focused on the straw effect of KTX. The main purpose of this study was to examine the straw effect of new KTX operation through constructing the indicator of interregional dependency, which is capable of reflecting whether the population became concentrated in Seoul or spread to other parts of Korea during the evolution of KTX.

Regarding this question, this study used a panel data model to conduct the empirical analysis. Overall, the larger the economic scale of the city of interest, the lower the level of dependency on other cities. The regression results confirm that the KTX connection will increase other cities' dependency upon Seoul; however, on the contrary, this effect is not significant with regard to the other four cities, which means the straw effect of KTX connection exists in terms of Seoul. Considering the robustness of our results, we introduced market access as an alternative independent variable, the regression result is consistent with our baseline results.

The potential contribution of this study is outlined below. First, we constructed an indicator of interregional dependency to reflect one city's level of dependency on another before and after the operation of KTX. Second, we established a more real-acts equation than the cross-section data model through an individual time-fixed panel data model, which integrated the information of individual and time to examine the effect of new KTX developments on interregional dependency. Third, in order to avoid the interference of lurking variables, we also controlled city characteristic variables and introduced market access as an alternative independent variable for the consideration of robustness. Moreover, the empirical results pertaining to the influence of new transport infrastructures on socio-economic development could be a guidance of business development around high-speed railway stations and urban planning in the future.

The results in this study underscore the importance of having a comprehensive assessment on the costs and benefits of new transport projects, particularly taking regional disparity, in terms of socio-economic development, into account. We anticipate that a failure to do so could potentially aggravate regional inequality in the long run, as well as lower the overall welfare level of society. Since the existing literature has not reached conclusive results on the HSR-regional economic development nexus (i.e., straw effect or sprawl effect) theoretically or empirically. Future research into this area could develop more reasonable dynamic models of the joint evolution of HSR constructions and regional economic development. Moreover, with the introduction of HSR in more countries worldwide, future study could replicate our results in other contexts and unpack the specific channel through which new HSR constructions affect local relative attraction. As for those large or federal

countries, the heterogeneity of socio-economic effects on regional development from HSR also needs further analysis.

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