# Agglomeration Shadows amid China's Urbanization: From a High-Speed Railway Perspective

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**Abstract:** *Using China's county-level panel data of 2007-2016, this paper verifies the existence of agglomeration shadows from an infrastructure development perspective. With high-speed railway (HSR) launch as a quasi-natural experiment, we find that the launch of HSR lines was followed by a decrease in GDP per capita of counties along the route by 2.6 percentage points. This conclusion remains valid after a series of robustness tests and the treatment of potential endogeneity problem. Mechanism analysis suggests that such effect is the most significant for counties within a distance of 97 to 195 km to the nearest central city, which is a manifestation of the "agglomeration shadows." We also uncover that HSR would spur economic growth for counties with favorable endowments. However, HSR also has a significant negative impact on permanent population in counties. When change in permanent population is taken into account, HSR's negative impact on the countywide economy becomes smaller. Shrinking permanent population in counties after HSR launch is a manifestation of such agglomeration shadows. HSR has facilitated the free flow of population. These findings point to the possibility that HSR may have induced regional economic equilibrium amid agglomeration.*

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## 1. Introduction

Over the past couple of decades, China's rapid economic growth has been accompanied by surging urbanization. In 2011, China's urbanization rate exceeded 50% for the first time in history, which marks the beginning of China's transition from a moderately urbanized country to a highly urbanized one. Recent years have seen some new developments in China's urbanization: Central cities in some regions scrambled to attract talent by lowering residency criteria or raising benefits. Provincial capitals have absorbed neighboring counties and prefectures into their jurisdiction as districts to undergird their primacy in respective provinces. On the other hand, small and medium-sized cities have suffered a brain drain and economic contraction. From 2008 to 2016, the GDP aggregate of regional central cities as a share of national total rose from 37.8% to 40.2%.[1] These developments are indicative of a new stage of China's urbanization in which economic factors concentrate in central cities at a rapid pace (Lu, 2016).

These new characteristics are consistent with the expectations of the core-periphery model in the

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[1] In this paper, central cities are defined as provincial capitals, municipalities directly under the central government, regional capitals and cities under separate planning (excluding Lasa).

new economic geography (NEG). With improving trade conditions, regional economic development is a process in which economic factors move from peripheral areas to core areas (Krugman, 1991; Krugman and Elizondo, 1996; Fujita *et al*., 2001). In the meantime, a unique urbanization phenomenon, i.e. agglomeration shadow, will occur. It means that a central city will absorb economic factors and create an economic shadow in its periphery, thus stifling the development of small cities. Based on this theory, we will investigate the existence of agglomeration shadows in China's urbanization process in the new era, as well as the boundaries of those shadows, to explain the new developments of China's urbanization process.

In the hierarchy of Chinese cities, there are prefecture-level cities and various county-level administrative areas under the jurisdiction of prefecture-level cities. Municipal districts constitute the center of a prefecture-level city, and are directly governed by the city government with respect to administrative, fiscal and economic affairs. Counties are geographically distant from a regional center.[2] They possess certain independence of administrative and fiscal powers and may institute local economic development plans. As such, counties in China are largely considered as independent from the central districts of a prefecture-level city and make up the hinterland of regional economic development, i.e. periphery. This paper aims to investigate the economic development of counties as the periphery and verify whether agglomeration shadows exist amid the economic development of counties in China.

Trade conditions play a pivotal role in the center-periphery model, and transportation infrastructure is a decisive factor of trade conditions (Faber, 2014; Baum-snow *et al*., 2017, 2020). Improving transportation infrastructure may substantially reduce trade cost and influence relative economic development between regions (Donaldson and Hornbeck, 2016). Since 2008, China has made tremendous progress in HSR construction across the country. Among various transportation infrastructures, HSR has garnered the most public attention. By the end of 2016, HSR lines in operation in the Chinese mainland exceeded 22,000 km. As a convenient mode of transportation, HSR has shortened the temporal and spatial distances between cities (Long *et al.,* 2017). For this reason, HSR may have contributed to agglomeration shadows amid economic development.

With the county-level panel data of 2007-2016, this paper investigates the relationship between China's HSR launch since 2008 and countywide economic development, and identifies whether agglomeration shadows exist in China's regional development. According to our DID analysis, HSR launch has reduced countywide GDP per capita by 2.6 percentage points, which is consistent with the expectations of the center-periphery model. Furthermore, we find that among counties served by HSR, those in a range 97-195 km away from the nearest central city recorded the sharpest decreases in their GDP per capita and permanent population. That is to say, the agglomeration shadow effect of central cities exists primarily within this critical range. Moreover, we also found that resource endowment may offset HSR's negative effects on countywide economic development. Specifically, counties with superior tourism resources recorded growth in their GDP per capita. Lastly, although HSR launch has negative effects on countywide economic development, such effects are less significant when changes in permanent populations are taken into account.

Our conclusions are compatible with the "equilibrium amid agglomeration" concept advocated by Lu and Chen (2008), Lu *et al*., (2012), Lu and Xiang (2014) and Lu (2017): HSR is conducive to the free flow of economic factors and facilitates economic agglomeration and regional equilibrium in a per capita sense. This paper's main contributions can be summed up as follows:

(1) Theoretically, this study has broadened our understanding of the core-periphery model. In the context of rapid urbanization, China's economic restructuring at the local level can be insightfully interpreted using the core-periphery model. In particular, this paper brings analysis of the core-periphery

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[2] Such a central region may be the prefecture-level city with jurisdiction over the county or the municipal district of another prefecture-level city.

model under the agglomeration shadow theory, and verifies that the agglomeration shadow theory under the core-periphery model is compatible with the concept of "equilibrium amid agglomeration".

(2) Empirically, this paper verifies the existence of agglomeration shadows resulting from transportation infrastructure and further identifies the general scope of agglomeration shadows. Since HSR development is conducive to the free flow of economic factors, counties with superior endowments are able to benefit directly from HSR launch. Those findings suggest that HSR development could be conducive to the equilibrium of China's urbanization amid agglomeration.

The remainder of this paper is structured as follows: Part 2 is literature review and theoretical hypothesis; Part 3 explains the econometric model and relevant data; Part 4 is a benchmark empirical analysis; Part 5 provides a mechanism analysis; Part 6 demonstrates how HSR could facilitate regional economic equilibrium amid agglomeration; the final section offers conclusions and policy implications.

## 2. Literature Review and Theoretical Hypothesis

Highly uneven spatial distribution of economic activity underpins the emergence of cities of all sizes. This phenomenon has been explained by Krugman (1991) based on increasing returns to scale. Proceeding from increasing returns to scale, scholars of the new economic geography (NEG) created a core-periphery model (Krugman, 1991; Krugman and Elizondo, 1996; Fujita *et al*., 2001). The core-periphery model considers that the centripetal force of economic factor agglomeration and the centrifugal force that works against such agglomeration have jointly led to the emergence of cities. While the centripetal force derives from external economies, market scale effect and knowledge spillovers, the centrifugal force derives from external diseconomies, including rising cost of transportation due to city expansion, congestion effect, pollution effect and competitive pressures. At a certain level of development when the centripetal force of a central city to attract production factors exceeds its centrifugal force and the centripetal force of other cities, economic factors start to concentrate in central cities.

Agglomeration shadow can be seen as a manifestation of the core-periphery model (Fujita *et al*., 2001; Bosker and Buringh, 2017; Hodgson, 2018). According to the agglomeration shadow theory, the manufacturing industry with higher marginal compensation will concentrate in the regional center with greater market potentials while agriculture will develop in the periphery. In a multi-city region, areas in between manufacturing hubs are referred to as agglomeration shadows. Distance is the key factor for the explanation of agglomeration shadows, which come into existence under the effects of centripetal and centrifugal forces. While regions adjacent to a central city may thrive on the market and economic spillovers of the central city (Xu e*t al*., 2010), regions far away from a central city may also thrive by becoming subregional hubs. In comparison, regions too far from a central city to benefit from its spillover effect but too close to become subregional hubs are the most vulnerable to the agglomeration shadow effect. Chen and Sun (2017) and Hodgson (2018) respectively verified the existence of agglomeration shadows in China and the US. Bosker and Buringh (2017) revealed that agglomeration shadows also existed in ancient European cities.

In the hierarchy of cities, trade cost between various cities is the most important determinant of a city's relative centripetal and centrifugal forces. With lowering trade cost in a certain development stage, a central city will boast greater market potentials and market access that attract economic factors. Meanwhile, economic factors start to move out from peripheral regions, giving rise to the agglomeration shadows in regional economic development (Fujita *et al*., 2001; Donaldson and Hornbeck, 2016; Bosker and Buringh, 2017; Hodgson, 2018). In regional economics, the regional economic development effects of transportation infrastructure as a decisive factor of trade cost have been a popular topic of research (Zheng and Kahn, 2013; Faber, 2014; Baum-snow *et al*., 2017, 2020; Qin, 2016; Lin, 2017). Among them, some studies have focused on regional hinterland: Faber (2014) found that China's National Trunk Highway System negatively affected countywide economic development, and considered such negative effects as compatible with the deepening of market integration. Qin (2016) examined the economic effects of China's railway acceleration on counties and discovered the negative effects of railway acceleration on the countywide economy due to falling fixed asset investment. Baum-Snow *et al*., (2020) divided prefecture-level cities into regional prime cities and non-prime cities, and found that expressway construction would harm the development of non-prime cities.

Since HSR launch helps reduce trade cost between regions, we put forth Hypothesis 1 based on the core-periphery model:

Hypothesis 1: HSR launch will hurt countywide economic development, causing the economic indicators of counties to decline in relative terms.

Second, the core-periphery theory predicts that most manufacturing activities will cluster in the city center that offers greater market potentials. Regions beyond a certain "critical distance" from a central city are less vulnerable to the latter's "siphon effect," allowing local manufacturing enterprises to thrive on the local market. However, regions too distant from a central city to benefit from its spillover effects but not far enough to develop into subregional hubs are vulnerable to the "siphon effect" of a central city, which may stymie their economic growth and give rise to "agglomeration shadows". Based on the above analysis, HSR will link central cities to peripheral small cities, lower interregional transportation cost, facilitate the flow of economic factors, and is likely to cause a divergence in economic development of small cities. That is, after an HSR is put into operation, an "agglomeration shadow" of a city's economic activity will occur in the middle of a few regional central cities. Hence, we put forth the following hypothesis:

Hypothesis 2: HSR's negative effects on countywide economic development can be explained with the agglomeration shadow theory, i.e. among counties served by HSR, those beyond a certain critical distance from the central city will experience the sharpest decline of countywide economic indicators.

Lastly, the question is how should we look at HSR's negative effects on the countywide economy and the phenomenon of agglomeration shadows? Judging by the urbanization experience of developed countries, it is normal for agglomeration shadows to occur as economic factors flow from peripheral to central cities (Lu, 2016). However, this process may be accompanied by widening interregional economic development gaps.

To cope with widening interregional economic divide, Lu and Chen (2008), Lu *et al*., (2012), Lu and Xiang (2014) and Lu (2017) called for China's urbanization to achieve "equilibrium amid agglomeration", i.e. the government should remove barriers to the free flow of economic factors such as the household registration (*hukou*) system and market segmentation, and give play to the agglomeration strengths of central cities to increase their economic aggregate and create spillover effects for economic hinterland to foster competitive industries, so as to achieve economic agglomeration and regional equilibrium in the per capita sense in real earnest.

Liang *et al*., (2013) also called for reforming China's household registration (*hukou*) system to promote the free flow of labor and optimize the size of cities. From the perspective of "equilibrium amid agglomeration," the emergence of agglomeration shadows is a positive process. By putting the phenomenon of agglomeration shadows in the context of "equilibrium amid agglomeration," we may derive an understanding at a deeper level: As a more convenient mode of transportation, HSR is conducive to the free flow of economic factors, which is a *sine qua non* for "equilibrium amid agglomeration".

Regional development paths may diverge due to different resource endowments, which represent various levels of agglomeration potentials that may attract different economic factors to agglomerate locally. This conclusion is extensively proven by the existing literature. Ellison and Glaeser (1999) noted that regions rich in mineral resources normally had a higher concentration of manufacturing activity; Faber and Gaubert (2019) demonstrated that rich tourism resources were conducive to the local service sector development. With a strong temporal and spatial compression effect (Long *et al*., 2017), HSR may reduce transportation cost, facilitate the free flow of economic factor, unleash the agglomeration potentials of resource-rich regions, and attract external capital for the development of local resources, thus contributing to local economic development. Counties with favorable resources are likely to thrive after HSR launch under the agglomeration effect, which is consistent with the "equilibrium amid agglomeration" concept. That is to say, regions should develop competitive industries based on advantageous local resources (Lu, 2016). Hence, we put forth the following hypothesis.

Hypothesis 3: HSR is conducive to the free flow of economic factors, allowing some counties served by HSR to thrive on their advantageous resource endowments, which could be ultimately conducive to the "regional economic equilibrium amid agglomeration".

## 3. Econometric Model and Data Explanation

### 3.1 Econometric Model Specification

This paper employs the county-level panel data of 2008-2016 (including counties, county-level cities and counties that became city districts in recent years, excluding the original city jurisdictions of prefecture-level cities before 2007) to investigate how newly launched HSR lines would influence countywide economic development. Given the asynchronous launch of HSR lines in various counties, we perform an estimation with a multi-phase DID approach. Our benchmark econometric model is specified as follows:

$$Y_{it}=\alpha_0+\beta_1 T_{it}+\theta X_{it}+region_t+year_t+\varepsilon_{it} \quad (1)$$

Where, $Y_{it}$ is the explained variable, i.e. the logarithm of GDP per capita (GDP aggregate of each country divided by registered population) for each county (ln (GDP per capita)). Since change in registered population is relatively stable, similar regression results will be obtained no matter GDP per capita or GDP aggregate is used as the explained variable. The former is employed in this paper because change in the administrative jurisdictions of some counties would cause discontinuity in economic aggregate, and this problem can be largely addressed by dividing GDP by registered population. $T_{it}$ is the core explanatory variable, i.e. $T_{it}=treated_i\times post_{it}$. If there was a railway line put into operation in county $i$ during the sample period, the value of $treated_i$ is 1; otherwise, it is 0; for the current and subsequent years when a HSR line was put into operation in a certain county, $post_{it}$ is 1; otherwise, it is 0. $T_{it}=1$ suggests that a sample is in the experiment group.

Unlike Qin (2016) and Zhang (2017) who identified counties with railway stations as in the experiment group, this paper identifies all counties along HSR routes as in the experiment group with the following considerations: (1) HSR lines put into operation after 2008 followed similar routes with the China's National Trunk Highway System that took shape before 2008. Regions along HSR lines had much better access to transportation. For counties without HSR stations, it is still easy to access nearby HSR stations via highway. (2) After 2012, local governments have intensified their competition for HSR stations, and many HSR lines have set up a station in each county. (3) With county government seat as the center of a county (Baum-Snow *et al*., 2017), the average distance between county center and the nearest HSR station is 8.67 km for counties with HSR stations and 21.64 km for those without. Their difference is limited.

Zheng and Kahn (2013) noted that HSR corridors would influence market potentials of cities along the route. That is to say, HSR's effects are not limited to cities with stations. Some studies suggest that HSR has a significant corridor effect, which would reshape the spatial economic structure of regions along the route (Wang *et al*., 2014). As such, this paper identifies the rules for the experiment group as follows: If there was an HSR line in actual operation in the jurisdiction of a county before June 30 in a certain year, the county in the current and subsequent years is then classified as in the experiment group; if there was an HSR line put into service after June 30, the county in the following and subsequent years is classified as in the experiment group.

This paper focuses on an analysis of how core-periphery economic interactions influence economic development in the periphery. As such, we include into the regression model a string of economic variables that may influence countywide economic development. Controlling for those variables helps identify the results of core-periphery economic interactions.[3]

$X_{it}$ is a group of control variables at the county level, which include the price index for the province of each county (*cpi*) to control for price factor; the logarithm of investment per capita in the county (1n *perinvest*) to control for the output effect of investment in each county; industrial structure index of each county, denoted by the share of the secondary industry in GDP ($ratio_2$) and the share of tertiary industry in GDP ($ratio_3$), to control for the effect of industrial structure on the output level in various counties; fiscal independence index (*inde*), denoted by the local general budgetary income of each county divided by its general budgetary spending, to control for the output effect of county fiscal capabilities; the logarithm of each county's general budgetary spending (1n *perexp*) controls for the level of public goods in each county, as well as county government size; the loan to GDP ratio (*loanratio*) of each county, denoted by the year-end balance of loans for each county divided by its GDP, controls for the level of financial development in each county; the logarithm of population density in each county (1n*density*) controls for the level of population aggregation in each county; lastly, since the change of counties into municipal districts may influence economic development of counties in question, we have also included a dummy variable for whether a county is changed into a municipal district in our regression analysis (*change*).[4]

Lastly, in equation (1), $region_i$ is the dummy variable for individual regions, $year_t$ is the dummy variable for time, and $\varepsilon_{it}$ is the residual error term. Since the earliest HSR line was put into operation in 2008, we specify the sample period as from 2007 to 2016 to ensure the availability of pre-phase data in each experiment group and meet the DID model's requirements.

### 3.2 Data Source and Explanations

Data in this paper are from two sources: First, HSR launch information published by the China National Railway Corporation and *China Railway Yearbook*. Since China's first real HSR (hourly speed above 200 km) - Beijing-Tianjin Intercity Railway - was put into operation in 2008 (Zhang, 2017; Zhou *et al*., 2018), we collect information about HSR lines put into service from 2008 to 2016. Second, county-level data are primarily from the *China Countywide Statistics Yearbook*, and missing values are supplemented by relevant data of provincial statistical yearbooks. Given the poor quality of the county data of the Tibet Autonomous Region, we have excluded such data.

In addition, this paper also employs information about China's expressway network in 2008 and geographical elevation maps and county maps from the National Geo-Information Public Service Platform for instrumental variable (IV) calculations. In calculating the instrumental variable, we reference Faber (2014), Bai and Ji (2018) and Zhang *et al*., (2018). Table 1 is the descriptive statistics of key variables.

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[3] By introducing a series of county-specific control variables, our regression results are HSR's "lower bound value" on countywide economic development. We are grateful to anonymous reviewers for their suggestions on the use of control variables in this study, but take sole responsibility for this paper.

[4] The dummy variable for the conversion of counties into districts is the same with the creation of multi-phase DID variable.

**Table 1: Descriptive Statistics of Key Variables**

| Variable | Definition | Sample size | Mean | Standard error | Min. | Max. |
|---|---|---|---|---|---|---|
| 1n *pergdp* | ln (GDP per capita) | 19,780 | 9.912 | 0.795 | 7.351 | 13.061 |
| *T* | Whether an HSR passes through | 19,780 | 0.094 | 0.292 | 0.000 | 1.000 |
| *cpi* | Provincial price index | 300 | 1.031 | 0.021 | 0.977 | 1.101 |
| *inde* | Fiscal independence | 19,756 | 0.332 | 0.242 | 0.007 | 5.149 |
| 1n *perinvest* | ln (per capita fixed asset investment) | 19,751 | 9.424 | 1.093 | 0.201 | 13.456 |
| 1n *perexp* | ln (per capita fiscal spending) | 19,755 | 8.281 | 0.750 | 4.055 | 12.164 |
| $ratio_2$ | Share of the secondary industry | 19,781 | 0.442 | 0.157 | 0.016 | 0.939 |
| $ratio_3$ | Share of the tertiary industry | 19,781 | 0.339 | 0.101 | 0.005 | 0.898 |
| *change* | Whether the county has been changed into a municipal district | 19,781 | 0.034 | 0.182 | 0.000 | 1.000 |
| 1n*density* | ln (population density) | 19,780 | 5.190 | 1.330 | 0.137 | 11.838 |
| *loanratio* | Balance of loans/GDP | 19,648 | 0.526 | 0.331 | 0.000 | 7.281 |

Source: *China Railway Yearbook*, *China Countywide Statistics Yearbook*, and the National Geo-Information Public Service Platform.

# 4. Empirical Analysis

## 4.1 Benchmark Regression Results

First of all, we examine the average treatment effect (ATE) of HSR on the economic growth of counties served by HSR based on Model (1). To address the potential heteroscedasticity and serial correlation problems, we cluster standard errors at the county level in all our regression analyses.

Table 2 is the benchmark regression results. Column (1) is full sample regression. Results suggest that the coefficient of core explanatory variable *T* is significantly negative at the 1% level, i.e. HSR launch has restrained economic growth in counties along the route. Based on Column (1), HSR launch would reduce countywide GDP per capita by 2.6 percentage points.

Furthermore, we divide counties in the experiment group into counties with stations and those without for regression based on Model (1), and the results are shown in Columns (2) and (3) of Table 2. The control group is consistent for both regressions, i.e. regression results in Column (2) are obtained by excluding county samples without stations, and regression results in Column (3) are obtained by excluding county samples with stations. Coefficients of core variables in both Columns (2) and (3) are significantly negative and share similar coefficients. Results in Columns (2) and (3) demonstrate the creation of experiment group to be reasonable from a regression perspective.

Faber's (2014) study on China's National Trunk Highway System found that China's expressway network construction had restrained economic growth in "peripheral counties". Since HSR routes are similar to those of the expressway network, the negative effect in our benchmark regression analysis could also stem from expressway. To exclude such effect, we perform two robustness tests: First, we limit the samples to counties already served by expressway in 2008, and if the regression coefficient of *T* remains significantly negative in the subsample regression, the negative effect of HSR launch on the countywide economy will be proven to exist. Second, we include a cross term between the dummy variable for counties served by expressway in 2008 and the dummy variable for year to control for the impact of expressway on economic development over time.

Our data include 737 counties that were connected to expressway in 2008. Column (4) is the result

**Table 2: Benchmark Regression Results**

| | Total samples | Counties with stations | Counties without stations | Controlling for the impact of expressway | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Explained variable | ln (per capita GDP) | | | | |
| T | -0.026*** (0.006) | | | -0.020** (0.008) | -0.017*** (0.007) |
| T × counties with stations | | -0.024*** (0.008) | | | |
| T × counties without stations | | | -0.030*** (0.010) | | |
| Constant term | 6.286*** (0.317) | 6.440*** (0.341) | 6.563*** (0.362) | 5.039*** (0.392) | 6.214*** (0.312) |
| Sample size | 19,642 | 18,808 | 18,650 | 7,280 | 19,642 |
| $R^2$ | 0.984 | 0.984 | 0.984 | 0.986 | 0.984 |
| Fixed effect for year | Yes | Yes | Yes | Yes | Yes |
| Fixed effect for individual regions | Yes | Yes | Yes | Yes | Yes |
| Sample period | 2007-2016 | 2007-2016 | 2007-2016 | 2007-2016 | 2007-2016 |

Notes: Numbers in parentheses are standard errors clustered at the county level. The controlled variables are included in all the regressions shown in the above table. *, ** and *** denote significance at 10%, 5% and 1%, respectively, and the same below.

of regression performed with data of the 737 counties from 2007 to 2016. Column (5) includes a cross term between the dummy variable for expressway and the dummy variable for year. Obviously, the coefficient of *T* remains significantly negative. This result has once again proven that HSR launch indeed has a negative effect on the countywide economy.

## 4.2 Re-identification of the Causal Relationship

HSR's effects on countywide economic development investigated in this paper could be subject to the problem of sample self-selection. To address the endogeneity problem thus incurred, this paper creates a time-dependent instrumental variable (IV), i.e. the instrumental variable of minimum cost ($cost\_iv_{it}$) for an IV regression. In calculating the instrumental variable of minimum cost, we define two cities at both ends of an HSR line put into service during 2008-2016 as node cities, and based on the node cities, create the minimum cost pathways for newly launched HSR lines. Then, we generate $cost\_iv_{it}$ based on the minimum cost pathways following the same method for generating $T_{it}$.

Table 3 is the regression results of the instrumental variable method. Column (1) is the first-stage regression results. Obviously, the instrumental variable $cost\_iv_{it}$ is significantly positively correlated with *T*. Column (2) discusses the exogeneity of the instrumental variable referencing Sun and Chen (2017), i.e. *T* and instrumental variable $cost\_iv_{it}$ are simultaneously included into regression. At this moment, the regression coefficient of $cost\_iv_{it}$ is insignificant, which indicates the exogeneity of the instrumental variable. Column (3) is the second-stage regression results, in which the coefficient of *T* is significantly negative. Regression results in Table 3 have once again proven the negative effects of HSR launch on countywide economic development.[5]

[5] Referencing Li *et al*. (2016), we have performed a pseudo-intervention test for DID regression, which has further verified the robustness of this paper's benchmark regression results. Specific results are available upon request.

**Table 3: Regression Results of the Instrumental Variable Method**

| | Stage 1 | Exogeneity test | Stage 2 |
|---|---|---|---|
| | (1) | (2) | (3) |
| Explained variable | T | ln (GDP per capita) | |
| T | | -0.020** | -0.037*** |
| | | (0.008) | (0.011) |
| cost_iv | 0.583*** | -0.010 | |
| | (0.024) | (0.009) | |
| Constant term | -1.267*** | 6.275*** | 6.253*** |
| | (0.338) | (0.317) | (0.300) |
| Sample size | 19642 | 19,642 | 19642 |
| $R^2$ | 0.709 | 0.984 | 0.935 |
| Fixed effect for year | Yes | Yes | Yes |
| Fixed effect for individual regions | Yes | Yes | Yes |
| Sample period | 2007-2016 | 2007-2016 | 2007-2016 |
| First-stage F value | | | 638.345 |

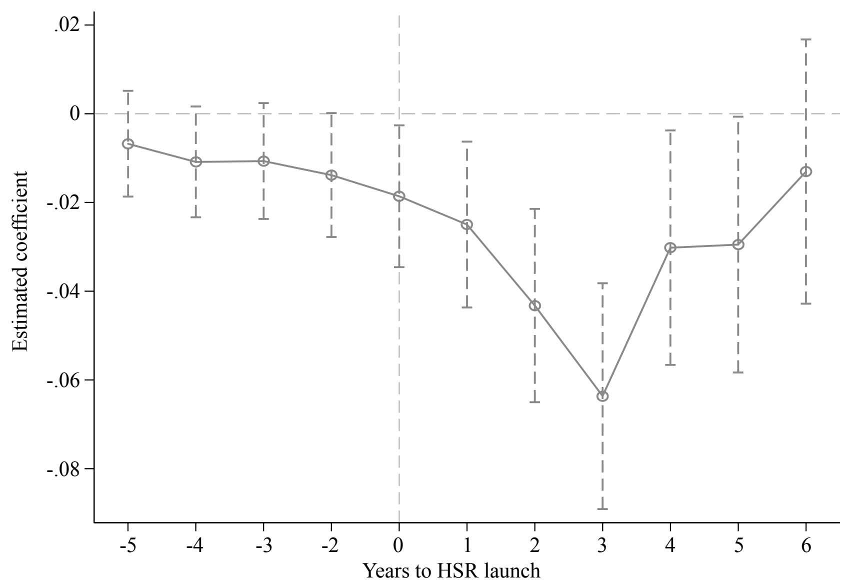


**Figure 1: Parallel Trend Test (vertical dashed lines indicate the upper and lower confidence intervals of the estimated coefficient)**

### 4.3 Parallel Trend Test

Lastly, we perform a parallel trend test for the DID regression referencing Li *et al*., (2016) and examine the dynamic changes of countywide economy before and after HSR launch.

We draw the regression coefficient of the parallel trend test into a dynamic diagram, as shown in Figure 1. After the HSR launch in 2008, the economic development trends of counties with and without HSRstarted to diverge, and the negative effects of HSR launch on the countywide economy began to emerge. Before HSR launch, the economic development trends of counties with and without HSR were parallel, i.e. our DID model is consistent with the parallel trend hypothesis. In addition, Figure 1 shows that the negative effects of HSR launch on countywide economic development started to diminish in the fourth year after the launch and vanished after the sixth year. The implication is that regional economic development may gradually reach a new equilibrium four or five years after HSR launch.

In this section, our analysis demonstrates that HSR launch has a negative effect on countywide economic development. After a series of robustness tests, this result still holds true, which indicates the correctness of Hypothesis 1.

# 5. Mechanism Analysis: Agglomeration Shadows

Section 4 demonstrates the negative effects of HSR launch on countywide economic development, thus verifying Hypothesis 1. In this section, we investigate whether such negative effects are a real reflection of the agglomeration shadows, i.e. whether Hypothesis 2 holds true.

## 5.1 Agglomeration Shadows: Empirical Analysis

From the perspective of distance, we demonstrate whether agglomeration shadows exist in the context of HSR launch. Referencing Hodgson (2018), we modify our econometric model as follows:[6]

$$Y_{it}=\alpha_0+\sum_{j=1}^{5}\beta_j\, dumj\times T_{it}+\theta X_{it}+region_i+year_t+\varepsilon_{it} \qquad (2)$$

Where, *dumj* is a group of dummy variables measuring the distance between counties in the experiment group and their respective central cities. It is created as follows: First, counties in the experiment group are ranked in the ascending order by the distance to a central city. If the distance between a county and a central city is in the left $20^{th}$ percentile, the value of this county sample is 1 in *dum1*; otherwise, it is 0. Similarly, if the distance between a county and a central city is in the left $20^{th}$ to $40^{th}$ percentiles, the value of this county sample is 1 in *dum2*; otherwise, it is 0, and so on and so forth.

Second, *dumj* is respectively cross-multiplied with *T* and included into the regression. Referencing Faber (2014) and Baum-Snow *et al*., (2020), we identify central cities as provincial capital cities, regional capitals, municipalities directly under the central government, and cities specially designated in the state plan already served by HSR in 2016. Distance is the shortest straight-line distance between a county's government seat and its nearest central city's government seat.[7] Following the concept of agglomeration shadows, if the negative effects of HSR launch on countywide economic development are a real reflection of agglomeration shadows, the coefficients of variables on both ends of the five variables from *dum1×T* to *dum5×T* should be greater than those in the middle. It is also likely that the coefficients of variables at the center are significantly negative, and those of variables at both ends are insignificant.

Table 4 shows the results of regression following equation (2). Results of Column (1) are consistent with the expectations, i.e. the coefficients of *dum1×T* and *dum2×T* are insignificant, and the coefficients of *dum3×T* and *dum4×T* in the middle is significantly negative. Yet the coefficient of *dum5×T* is also insignificant. Since there was no HSR in Yunnan Province, Ningxia Hui Autonomous Region and Inner Mongolia Autonomous Region by 2016, we perform another sub-sample regression analysis by excluding these three provinces

in Column (2). In Column (3), we include a cross term between the dummy variable for expressway and the dummy variable for year to control for the impact of expressway. Similarly, agglomeration shadows still exist.

In addition, although straight-line distance serves as a more exogenous grouping criterion (Faber,

[6] Following the same approach, instrumental variables corresponding to $dumj\times T_{it}$ are created from cost_iv for a two-stage regression (Jedwad *et al*., 2017). There is no significant change in the regression results of this and subsequent sections, and the conclusion of agglomeration shadow remains valid.

[7] In 2016, Yunnan Province, the Inner Mongolia Autonomous Region and the Ningxia Hui Autonomous Region were also not connected to high-speed railway in addition to the Tibet Autonomous Region.

**Table 4: Agglomeration Shadows**

| | Straight-line distance to a central city | | | Expressway distance to a central city | | |
|---|---|---|---|---|---|---|
| | Total-sample regression | After exclusion of the three provincial samples | Control for the impact of expressway | Total-sample regression | After exclusion of the three provincial samples | Control for the impact of expressway |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Explained variable | Ln (GDP per capita) | | | | | |
| dum1×T | -0.006 | 0.003 | 0.006 | -0.013 | -0.005 | -0.002 |
| | (0.015) | (0.014) | (0.015) | (0.014) | (0.014) | (0.014) |
| dum2×T | -0.023 | -0.014 | -0.011 | -0.025* | -0.017 | -0.016 |
| | (0.015) | (0.015) | (0.015) | (0.014) | (0.014) | (0.014) |
| dum3×T | -0.033** | -0.025* | -0.024* | -0.032** | -0.024* | -0.023 |
| | (0.013) | (0.013) | (0.013) | (0.014) | (0.014) | (0.014) |
| dum4×T | -0.051*** | -0.043*** | -0.044*** | -0.038*** | -0.030** | -0.031** |
| | (0.013) | (0.013) | (0.013) | (0.012) | (0.012) | (0.012) |
| dum5×T | -0.017 | -0.009 | -0.013 | -0.021 | -0.013 | -0.013 |
| | (0.012) | (0.012) | (0.012) | (0.014) | (0.014) | (0.014) |
| Constant term | 6.288*** | 6.517*** | 6.214*** | 6.291*** | 6.520*** | 6.218*** |
| | (0.317) | (0.352) | (0.312) | (0.317) | (0.353) | (0.312) |
| Sample size | 19,642 | 17,542 | 19,642 | 19,642 | 17,542 | 19,642 |
| $R^2$ | 0.984 | 0.983 | 0.985 | 0.984 | 0.983 | 0.985 |
| Fixed effect of year | Yes | Yes | Yes | Yes | Yes | Yes |
| Fixed effect of individual regions | Yes | Yes | Yes | Yes | Yes | Yes |
| Sample period | 2007-2016 | 2007-2016 | 2007-2016 | 2007-2016 | 2007-2016 | 2007-2016 |

2014), it may introduce a measurement error. Based on China's HSR network in 2016, we calculate the railway distances between counties with HSR and their respective central cities, and group our samples according to railway distance for a robustness test with regression results shown in Columns (4)-(6). Obviously, agglomeration shadows still exist.

The above results indicate that the negative effects of HSR launch on countywide economic development were primarily suffered by counties at a medium distance from central cities. Measured by the distance to central cities, the negative effects of HSR launch on the countywide economy exhibit an inverted U-shaped pattern. As shown in Column (2) of Table 4, agglomeration shadows are roughly in the range between 97 km (*dum3×T*) and 195 km (*dum4×T*) to a central city.

### 5.2 Agglomeration Shadows: Competing Hypothesis and Robustness Test

As noted in our theoretical analysis, agglomeration shadows originate from the centripetal and centrifugal forces of economic factors from the perspective of central cities. Hence, we introduce central cities for a heterogeneity analysis of the distance between counties with HSR and their nearest central cities to verify the existence of agglomeration shadows. However, there is one competing hypothesis that may threaten the credibility of the results, i.e. access to HSR may also reduce GDP per capita of central cities, i.e. HSR has a negative impact on economic development of all regions, and no agglomeration shadow exists.[8]

[8] We thank anonymous reviewers for their suggestions here, but take sole responsibility for this paper.

**Table 5: Competing Hypothesis**

| | Basic regression | | Cap control for the impact of expressway |
|---|---|---|---|
| | (1) | (2) | (3) |
| Explained variable | GDP per capita ratio (by household registration) | | |
| T | -0.008**<br>(0.004) | | |
| dum1×T | | -0.000<br>(0.013) | 0.004<br>(0.013) |
| dum2×T | | -0.003<br>(0.007) | 0.001<br>(0.007) |
| dum3×T | | -0.013**<br>(0.006) | -0.010*<br>(0.006) |
| dum4×T | | -0.017***<br>(0.006) | -0.014**<br>(0.006) |
| dum5×T | | -0.005<br>(0.007) | -0.003<br>(0.007) |
| Constant term | -1.166***<br>(0.194) | -1.164***<br>(0.193) | -1.186***<br>(0.191) |
| Sample size | 19,642 | 19,642 | 19,642 |
| $R^2$ | 0.963 | 0.963 | 0.963 |
| Fixed effect of year | Yes | Yes | Yes |
| Fixed effect of individual regions | Yes | Yes | Yes |
| Sample period | 2007-2016 | 2007-2016 | 2007-2016 |

To verify the competing hypothesis, we replace the explained variable with the ratio between GDP per capita of each county and GDP per capita of central cities ("GDP per capita ratio", the same below). If the GDP per capita ratio decreases after HSR launch, the implication is that the relative GDP of counties with HSR will decrease more, and the competing hypothesis does not hold true. Table 5 shows the regression results. Where, Column (1) shows that HSR launch has indeed led to a decrease in the GDP per capita ratio of counties.[9] Results in Column (2) suggest that decrease in the GDP per capita ratio of counties has also followed a pattern of agglomeration shadows, i.e. the range of 97 km (*dum3×T*) to 195 km (*dum4×T*) from a central city is an agglomeration shadow. In Column (3), we also include a cross term between the dummy variable of expressway and the dummy variable of year, and the results remain robust.

This section has verified the correctness of our Hypothesis 2, i.e. HSR's negative effect on countywide economic development can be explained with the agglomeration shadow theory. That is, among counties with HSR, regions with a certain critical distance from the central cities (roughly from 97 km to 195 km) experienced the sharpest decreases in their regional economic indicators.

## 6. Equilibrium amid Agglomeration

After Hypothesis 2 is verified in Section 5, this section will discuss the negative effects of HSR

[9] Such a decrease can be attributable to the following circumstances: First, HSR launch was followed by an increase in the GDP per capita of central cities; second, HSR launch was followed by a decrease in the GDP per capita of counties. If any or both cases occur, the competing hypothesis will not hold true. Of course, there is another more extreme possibility, i.e. both the central cities and the counties with HSR experienced decreases in their GDP per capita, and the latter's decrease was more significant. As noted in this paper's introductory section, the GDP of central cities as a share of national total rose from 37.8% to 40.2%. The second possibility is, therefore, highly unlikely.

launch on the countywide economy from the perspective of change in permanent county population.[10] By introducing the variable of permanent county population, we will verify Hypothesis 3.

### 6.1 HSR Launch and Change in Permanent Population

Compared with traditional modes of transportation, HSR is rapid, punctual, safe and comfortable. For these strengths, HSR is conducive to the flow of population, especially highly qualified labor force (Lin, 2017). In this section, we put together data of permanent population[11] in most counties across China from 2010 to 2016 to investigate whether HSR launch will affect the size of permanent population with the logarithm of permanent county population as the explained variable.

Due to limited data availability, we cannot access the county-specific permanent population data before 2010, and pre-phase data are lacking for some experiment group samples. Compared with the DID method, results estimated with the instrumental variable method could be more reliable. Hence, we have employed the instrumental variable method for regression.[12] Table 6 is the regression results with the logarithm of permanent county population as the explained variable. Explained variable in Column (1) is the logarithm of permanent population, and the regression coefficient of $T$ is significantly negative, indicating that HSR launch would cause an outflow of permanent population from counties with HSR stations.

For a comparative analysis, we have replaced the explained variable with the logarithm of registered population. Column (2) is the regression results of the instrumental variable (IV) method from 2010 to 2016, and Columns (3) and (4) are IV and DID regression results for samples from 2007 to 2016. In those three columns, $T$'s coefficients are all insignificant and very close to 0, which indicates that HSR launch would not affect the registered population of counties with stations. Regression results in Table 6 suggest that HSR launch would influence the size of permanent county population, and that in the absence of material change to the *hukou* system, HSR launch would not have any impact on the size of registered population (Au and Henderson, 2006; Faber, 2014).

Lu and Chen (2008), Lu *et al*., (2012), Lu and Xiang (2014), Lu (2017) and many others have called for China's overall economic development to pursue "equilibrium amid agglomeration", a key aspect of which is to promote infrastructure connectivity and the free flow of factors across regions. Our findings suggest that HSR has played a very positive role in promoting the free flow of economic factors, not least population. Long *et al.,* (2017) suggests that HSR development also has a positive effect on the free flow of capital.

To further verify the existence of agglomeration shadows, we employ the logarithm of permanent populations as the explained variable for an IV regression following equation (4). Referencing Jedwad *et al*., (2017), we perform a two-stage regression by generating instrumental variables from $cost\_iv_{it}$ corresponding to $dumj \times T_{it}$. Results of Table 7 are similar to results of Table 4, i.e. the coefficient of $dum3 \times T$ is significantly negative while the other four coefficients are insignificant. This also suggests that the negative effects of HSR launch on permanent county population were primarily suffered by counties with HSR in the middle between central cities. Among various economic factors, population is relatively vibrant, and the effects of HSR launch on permanent county population can be regarded as a manifestation of the agglomeration shadows.

### 6.2 Heterogeneity Analysis: HSR Launch for Regions with Differentiated Resource Endowments

Differences in resource endowments influence the development pathways of various regions in

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[10] In the interest of length, no robustness test for expressway is performed in the empirical regression in this section. The cross term between the dummy variable of expressway and year does not affect the robustness of regression in this section.

[11] County-specific population data of Heilongjiang Province, Jilin Province, Xinjiang Uyghur Autonomous Region, Qinghai Province and the Inner Mongolia Autonomous Region after 2010 are not available. We have thus excluded sample counties of these five provincial-level regions in this part of regression.

[12] Regression with DID method for two-way fixed effect will not affect the robustness of regression in this section.

**Table 6: Railway Launch and Population Change**

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Explained variable | ln (permanent population) | ln (registered population) | | |
| T | -0.012** | 0.004 | -0.002 | -0.004 |
| | (0.005) | (0.004) | (0.004) | (0.003) |
| Constant term | 12.642*** | 11.950*** | 12.413*** | 12.405*** |
| | (0.093) | (0.259) | (0.233) | (0.234) |
| Sample size | 11,555 | 13,753 | 19,642 | 19,642 |
| $R^2$ | 0.079 | 0.153 | 0.222 | 0.222 |
| Instrumental variable | Yes | Yes | Yes | No |
| Fixed effect of year | Yes | Yes | Yes | Yes |
| Fixed effect of individual regions | Yes | Yes | Yes | Yes |
| Sample period | 2010-2016 | 2010-2016 | 2007-2016 | 2007-2016 |

**Table 7: Manifestations of Agglomeration Shadows on Permanent Population**

| | (1) |
|---|---|
| Explained variable | ln (permanent population) |
| dum1×T | -0.002 |
| | (0.011) |
| dum2×T | -0.004 |
| | (0.008) |
| dum3×T | -0.020** |
| | (0.010) |
| dum4×T | 0.004 |
| | (0.010) |
| dum5×T | -0.007 |
| | (0.008) |
| Constant term | 12.652*** |
| | (0.091) |
| Sample size | 11,555 |
| $R^2$ | 0.082 |
| Instrumental variable (IV) method | Yes |
| Fixed effect for year | Yes |
| Fixed effect for individual regions | Yes |
| Sample period | 2010-2016 |

profound ways (Ellison and Glaeser, 1999; Faber and Gaubert, 2019). The notion of “equilibrium amid agglomeration” also calls for fostering competitive industries based on local resources (Lu, 2016). Lin (2017) demonstrated that HSR launch would significantly increase employment in the tourism industry in prefecture-level cities. Hence, we create a dummy variable ($resource_i$), which is defined as 1 if a county boasts superior tourism resources; otherwise, it is 0. This dummy variable is measured by whether a county had any national 5A tourist attraction from 2007 to 2018. This period is extended till 2018 because the recognition of 5A tourist attractions was a lengthy process. Similarly, we introduced the product of multiplication between *T* and *resource* into regression with results shown in Column (1) of Table 8. According to Column (1), *T*’s coefficient remains significantly negative, *T*×*resource*’s

**Table 8: Tourism Resource Endowment and HSR Launch**

| | (1) |
|---|---|
| Explained variable | Ln (GDP per capita) |
| T | -0.030*** |
| | (0.007) |
| T× resource | 0.037** |
| | (0.017) |
| Constant | 6.290*** |
| | (0.316) |
| Sample size | 19,642 |
| $R^2$ | 0.984 |
| Fixed effect for year | Yes |
| Fixed effect for individual regions | Yes |
| Sample period | 2007-2016 |

coefficient remains significantly positive, and their absolute values are greater than *T*. That is to say, counties rich in tourist attractions may benefit from HSR launch by attracting tourists from adjacent cities. With an inflow of factors, those counties registered an increase in GDP per capita by 0.7%.

Regression results of the above sections have once again verified Hypothesis 2, as well as the first part of Hypothesis 3, i.e. HSR launch is conducive to the free flow of economic factors, and counties with advantageous resource endowments served by HSR may reap development dividends from access to HSR.

### 6.3 HSR Launch, Change in Permanent Population and Economic Development

In the above analysis, we use GDP per capita for registered population as the explained variable. Given that each region's registered population is relatively constant, decrease in GDP per capita for registered population is more indicative of the economic size of counties with HSR.As shown in the results of the previous section, HSR launch may also cause a county's permanent population to shrink. If change in permanent population is taken into account, HSR may have a smaller negative effect on the GDP per capita of counties served by HSR.

To verify this guess, we will perform a regression analysis after re-calculating countywide GDP per capita for *permanent population* and comparing with the regression results calculated with GDP per capita for *registered population*. Table 9 presents the regression results. In comparing Column (1) with Column (3), we may find that if change in permanent population is taken into account, HSR indeed will have a much smaller impact on GDP per capita, i.e. change in permanent population will partially offset the negative effect of HSR on countywide GDP per capita, which is an essential element of the "equilibrium amid agglomeration" concept. As shown in Columns (2) and (4), agglomeration shadows still exist after samples of 2010 to 2016 are employed for an instrumental variable (IV) regression; in Column (4), the absolute values of regression coefficients of the five cross terms are all somewhat smaller than the values in Column (2). With changing permanent population taken into account, the phenomenon of agglomeration shadows will diminish, which is consistent with the "equilibrium amid agglomeration" concept.

As mentioned before, this paper aims to unravel the negative effects of HSR launch on the countywide economy and the consequent agglomeration shadows. Faber (2014) considered transportation infrastructure improvement as a necessary condition for regional economic integration. After the reduction of trade cost, the relative decline of economic volume in the hinterland was

**Table 9: Comparison between GDP per Capita for Permanent Population and GDP per Capita for Registered Population**

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Explained variable | ln (GDP per capita for registered population) | | ln (GDP per capita for permanent population) | |
| T | -0.042***<br>(0.012) | | -0.029**<br>(0.012) | |
| dum1×T | | -0.015<br>(0.026) | | -0.014<br>(0.031) |
| dum2×T | | -0.042**<br>(0.019) | | -0.040*<br>(0.021) |
| dum3×T | | -0.048**<br>(0.019) | | -0.025<br>(0.020) |
| dum4×T | | -0.047***<br>(0.015) | | -0.042***<br>(0.014) |
| dum5×T | | -0.011<br>(0.013) | | -0.006<br>(0.012) |
| Constant term | 3.974***<br>(0.383) | 3.982***<br>(0.384) | 3.490***<br>(0.367) | 3.490***<br>(0.367) |
| Sample size | 11,555 | 11,555 | 11,555 | 11,555 |
| $R^2$ | 0.894 | 0.894 | 0.890 | 0.890 |
| IV method | Yes | Yes | Yes | Yes |
| Fixed effect for year | Yes | Yes | Yes | Yes |
| Fixed effect for individual regions | Yes | Yes | Yes | Yes |
| Sample period | 2010-2016 | 2010-2016 | 2010-2016 | 2010-2016 |

accompanied by increases in overall economic efficiency and economic output. From the perspective of “equilibrium amid agglomeration”, decreasing trade cost will facilitate the free flow of economic factors and lead to the convergence of per capita income between central and peripheral regions. Hence, the negative growth effect of HSR launch on the countywide economy could be a necessary adjustment process (Lu, 2016, 2017). According to Figure 1 based on the event study method, the negative effects of HSR start to diminish three to four years after HSR launch, and such a gradual decrease of negative effects may represent a necessary adjustment process. Our research indicates that with changing permanent population taken into account, HSR’s negative effect on countywide GDP per capita would be less severe, and counties with advantageous resource endowments could directly benefit from HSR launch. These findings can be seen as indirect empirical evidence of “equilibrium amid agglomeration”. Research in this section has demonstrated the correctness of Hypothesis 3.

## 7. Conclusions and Policy Implications

With high-speed railway (HSR) lines put into operation during 2008 and 2016 as a quasi-natural experiment, this paper investigates the effects of infrastructure development on the countywide economy. Results suggest that HSR launch since 2008 was accompanied by a decrease in countywide GDP per capita by 2.6 percentage points. Results of the parallel trend test indicate that the negative effects of HSR on the countywide economy became evident three to four years after HSR launch.

Further mechanism analysis uncovers that the negative effects of HSR launch on the countywide economy are consistent with the agglomeration shadows of the core-periphery model, the scope of which is primarily 97 km to 195 km from the central cities. Moreover, the freer flow of economic factors after HSR launch will reduce permanent population of counties with HSR,and change in permanent population also follows a pattern of agglomeration shadows.

With change in permanent population taken into account, HSR has a smaller negative impact on the GDP per capita of counties, which is consistent with the concept of "equilibrium amid agglomeration".

This study further finds that although HSR will cause resources to concentrate in central regions, when counties also boast advantageous resource endowments, HSR may also draw resources to those counties and spur their economic growth. Specifically, counties with favorable tourism resources may benefit from HSR launch.

In the new era of China's transition from a moderate to a high degree of urbanization, HSR will link central cities with the hinterland, reduce trade cost, facilitate the free flow of economic factors, and induce a readjustment of China's overall economic structure following the core-periphery model. HSR is conducive to not only the attractiveness of central cities, but the flow of resources to counties with favorable resource endowments (such as tourist attractions) for their economic growth. In the long run, HSR will deepen regional economic integration and finally contributing to the "regional economic equilibrium amid agglomeration".

This study is of great policy significance: While some peripheral regions suffer from overall economic restructuring, a key question for local governments is how to cope with such shocks based on their respective strengths. Local governments in the agglomeration shadows should not only increase their transportation connectivity, but more importantly, take HSR as an opportunity, give play to local resources, increase exchanges with central regions by means of HSR, proactively attract an inflow of factors, and adopt development strategies suitable to local conditions for economic growth. CE

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