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Does High-Speed Rail Stimulate Urban Land Growth? Experience from China

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Abstract

This paper aims to measure the impact of HSR on urban land growth and to explore how the impact varies between different types of cites. Since HSR route planning decisions are influenced by the economic status of cities *en route*, whether a city gets an HSR station is likely to be endogenous to its economic growth and land development rate. To address this endogeneity, we adopt a Two-period Panel Data Instrumental Variable model using post road network in the Ming Dynasty and locations of military bases as instrumental variables. Results show that being connected to the HSR network on average leads to a 11.2% faster rate of growth of urban built-up areas. More interestingly, we document substantial heterogeneity in this impact based on the size and location of cities. Causes and mechanism for such heterogeneity are also elaborated, together with the policy and planning implications.

Keywords: high-speed rail (HSR), land development, transportation planning, new town, Two-period Panel Data Instrumental Variable model

1. Introduction

Worldwide development of high-speed rail (HSR) started in 1964 when the first commercial line began operations in Japan. Europe developed its first HSR line, the Florence–Rome "Direttissima" line in 1978. Since the 1990s, China has invested heavily in building the world's most extensive HSR network (Jiao *et al.*, 2014). Due to its comfort, convenience, safety and punctuality, HSR has become the most popular and reliable mode of short-to-medium-distance intercity travel across a variety of income levels worldwide (Campos and de Rus, 2009; Givoni and Banister, 2012; Sun, et al., 2020).

It is a generally accepted principle in urban economics and urban geography that a city's access to external resources is constrained by the extent and speed of regional transportation infrastructure. HSR can substantially shorten intercity travel times and reduce travel expenses, facilitating changes in urban spatial structure at the municipal level while creating new patterns of winners and losers at the regional level (Cao & Zhu, 2017; Deng et al., 2020; Pan, et al., 2020; Shao et al., 2017; Wang & Duan, 2018; Zhu *et al.*, 2015; Zhu and Guo, 2021). The improved mobility promoted by HSR facilitates a city's access to labour, capital, and markets, enhancing its original resource endowment and market potential. The classic theory of agglomeration economies indicates that this enhanced labor pooling, input and consumer market access, and knowledge spillover stimulates economic growth (Marshall, 1920). It follows that urban land, as an important input for urban production, is also likely to be expanded to accommodate the additional input of labor and capital for larger-scale production. However, Zheng & Kahn (2013) point out that the enhanced connectivity between major urban centers and smaller urban centers may also provide people with an escape from the negative effects of megacities, such as soaring rent, without isolating them from the benefits. HSR makes it easier for people to live in smaller nearby cities and commute into megacities daily for work, or for companies to move to smaller cities with lower rents and cheaper factors of production while remaining within easy reach of clients in larger cities (Zheng & Kahn, 2013). This may serve as a counterforce against expansion in some of the largest urban areas. While the preponderance of the evidence suggests HSR connectivity is likely to lead to urban land growth, there are reasons to question whether such effects hold across different types of cities.

It can be observed that the impact of HSR on land development and urban spatial structure (i.e., the patterns of urban decentralization) is different for large cities and small or medium-sized cities, as well as for cities in different geographical regions, e.g., coastal cities vs. inland cities (Chen et al., 2020; Long et al., 2018; Zhu et al.,2015; Zhu et al. 2020). This is often related to the location of HSR stations, i.e., central versus peripheral locations (Ahlfeldt and Feddersen 2018; Beckerich et al. 2019). The existing literature suggests that, in addition to market forces, municipal governments play a vital role in driving urban land growth. Municipal governments are central stakeholders in the HSR network construction process, especially in planning and building their respective HSR stations and 'HSR new towns'. Seeking to utilize newly built HSR stations as an anchor to cultivate new sources of economic growth, many local governments have invested heavily in HSR new town projects, further expediting and intensifying land development. Chen and Haynes (2015) provide similar explanations regarding the role of local government on urban land growth in the process of

HSR development. However, different municipal governments have varying resources to bring to bear to facilitate land development, as well as different levels of bargaining power to negotiate for optimal HSR station locations. This may shape how land development occurs around HSR stations. While those cities with greater negotiating power are more likely to obtain HSR stations well-integrated with the existing city that contribute to agglomeration economies and foster gradual and sustainable growth, those with little negotiating power may be left with stations that are far from the existing city and generate sprawl, necessitating long commutes that undermine urban sustainability. The location of HSR stations and the forms of land development spurred by them thus have implications for both economic development and environmental sustainability.

While a few qualitative studies have discussed the influence of HSR on land development and urban spatial structure (see for example, Zhu *et al.*, 2015), there are only a limited number of studies starting to address these questions quantitatively (see for example, Deng et al., 2020; Zhu et al., 2020). Several recent studies have examined the impact of HSR on urban land structure changes (Chen et al., 2020) and on land price (Huang and Du, 2020; Chen et al., 2019). However, it remains under-researched to what extent investments in HSR have accelerated the rate of land expansion at the municipal level. This study aims to address this gap in the literature. In addition to quantifying the impact of HSR on land development rates, we also aim to examine the heterogeneity of this impact on cities of different sizes and in different geographical regions.

To address these questions, we use a two-period panel data model for 2004 and 2015. Because the rate of land growth in a city is associated with its economic development and may inversely affect its preferential status in being chosen for HSR construction by the central government, whether a city has HSR access could be endogenous. We apply two instrumental variables to address this potential endogeneity issue: 1) the post road network in the Ming Dynasty and 2) the locations of military bases in 2005. Our empirical findings indicate that HSR tends to be influential in facilitating the growth of urban built-up land in small cities or inland province cities, whereas its impact in large cities or coastal province cities is insignificant. We then elaborate on two mechanisms that could explain this heterogeneity: (a) different bargaining power of municipal governments in negotiating with the Ministry of Railways to determine the location of their HSR stations; and (b) local governments' reliance on land-based fiscal revenue and local officials' ideology of political entrepreneurism.

As HSR new towns are widely seen by Chinese urban planners as a key mechanism for reshaping cities, this research can inform decision-makers engaged in the planning and construction of HSR new towns in China. More importantly, as many other countries and regions are also proposing their own HSR systems, this research could have valuable international implications for urban planning and development in these regions as well.

2. Literature Review

There are a large number of studies examining the impact of HSR on economic and urban population growth. Both in China and in other regions, studies find that HSR development is associated with economic growth (Ahlfeldt & Fedderson, 2018; Jia et al., 2017). Scholars theorize that HSR development expands the access of particular cities to nearby labor and input markets, thereby spurring economic specialization and growth (Lin, 2017). Jia et al. (2017) find that HSR is associated with positive effects on GDP growth, while Lin (2017) finds that it is associated with growth in aggregate city employment, especially in tourism-related and skilled employment. Studies of night-time light image data also suggest that HSR development is associated with growth in economic activity, especially when HSR stations are located close to the urban core and when cities have relatively higher levels of prior economic development (Zheng et al.,2019; Niu et al., 2021). Meanwhile, other studies indicate a strong connection between the introduction of high-speed rail and urban population growth. Nakamura and Ueda (1989) and Obermauer and Black (2000) both find higher rates of population growth in cities connected to Japan's Shinkansen HSR, as compared to cities without HSR. Diao (2018) examines cities with HSR stations in China and finds that they experienced better accessibility, significant economic advantages, and greater population growth after the introduction of HSR. In a case study in Turkey, Beyzatlar (2011) conducts a co-integration and causality test and discovers that the construction of railway infrastructure led to increased population density in both in the long term and short term. Kotavaara et al. (2011) find that railway network development in Finland explains urban population growth with remarkable accuracy. However, these empirical results are also contested. In a study on HSR towns in Britain, Chen and Hall (2011) find that both HSR and non-HSR towns show substantial increases in population. Schwartz (2011) even find that an overly dense railway network might have a negative impact on population growth.

In addition to economic and population growth, scholars also examine the effect of HSR development on land and housing prices. A number of studies show that HSR development leads to growth in land and housing prices, as would be expected with heightened economic growth and a growing population (Chen & Haynes, 2015; Huang & Du, 2021; Wang et al., 2018; Zheng & Kahn, 2013). Huang and Du (2021) show that the effects of HSR are more prominent for the commercial land sector, while it also has a strong positive effect on residential land prices. Both the presence of an HSR station and frequency of train service affect land prices (Wang et al., 2018). Moreover, Zheng and Kahn (2013) find that cities not directly connected to the HSR network but near an HSR station city also experience land premiums as a result of HSR development. In terms of heterogeneity by city type, land premiums from HSR development are larger in lower-ranking cities compared to first-tier economic centers, possibly due to the already heated land markets in first-tier cities (Huang & Du, 2021). Similarly, housing premiums deriving from HSR development are also greater for small and medium size cities than for first-tier cities (Chen & Haynes, 2015).

Thirdly, a number of studies examine the impact of HSR connection on urban morphology or urban spatial structure. Hall (2009) identifies three different urban development models based on the different positioning of HSR stations. In the first type, the HSR station is located in the urban center and adjacent to the CBD area, as is the case with the Beijing South Railway Station and London's King's Cross-St Pancras Station. In the second type, the HSR station is located at the edge of the city, connected to but separated from the existing urban core and usually forming a new sub-center within the urban area. Examples include Tianjin South Railway Station and London's Stratford Station. In the third type, the HSR station is located even further away from the existing urban area. This kind of pattern is especially distinguishable with the growth of a periphery "edge city" around the station. Shin-Yokohama Station, London's Ebbsfleet Station, and Suzhou New District Railway Station are examples of this type.

HSR has been described as a "catalyst for the restructuring of urban systems", potentially leading to both agglomeration and diffusion effects in the broader metropolitan area (Yin et al., 2015). While HSR stations positioned in the urban core may facilitate the regeneration of old city centers, enhance agglomeration economies and stimulate re-urbanization, HSR stations of the latter two types potentially transform the urban morphology and spur the process of decentralization and diffusion (Zhu et al., 2015). Bellet (2019) studied the reconstruction of HSR stations in Spain and argued that the new infrastructure was accompanied by major urban renewal and urban transformation projects; HSR acted as an effective and efficient catalyst for redevelopment not only of the station surroundings but also the physical and functional structure of the city as a whole. Chen et al. (2020), using a land transaction dataset covering 285 Chinese cities, examine how HSR development affects the diversity of urban land use, finding that the introduction of HSR tends to decrease industrial land use and increase commercial and logistics related land-use, leading to a more diversified land-use structure overall. They find that greatest enhancement in land-use diversity is found in Tier-2 cities. Zhu et al. (2015) study the different patterns of HSR-driven new town development in China and argue that development patterns might vary according to city size and bargaining power. Based on a case study of the Beijing-Shanghai HSR line, Yu et al. (2012) suggest that HSR facilitates suburbanization for major cities *en route*. In all cases, HSR has been found to have major impacts on the evolution of urban spatial structures.

Finally, a small number of recent studies have begun to examine the impact of HSR on urban land expansion. The diffusion effect or "urban expansion effect" triggered by HSR is especially prevalent in China, where most HSR stations were built in urban edge or suburban areas, leading to the physical expansion of urban areas (Wang et al., 2013). Wang et al. (2019), examining the Yangtze River Delta region, find that the urban expansion rate of HSR cities is higher than non-HSR cities, and that the urban expansion rate around HSR stations is higher than in the city at large, tending to shift the center of gravity in HSR cities. They find that effects are most prominent in Tier-2 cities. Zhang et al. (2020) similarly find a connection between HSR and urban land expansion in the middle Yangtze region. Zhu et al. (2020), focusing on a sample of 35 megacities, find that both the presence of an HSR station and the number of HSR stations are associated with urban expansion and that effects are more prominent in the less developed regions of western China than in the more developed eastern region. While these studies strongly suggest that HSR leads to urban expansion, they focus on geographically or typologically limited samples. Long et al. (2018) draw on a broader sample of 285 cities and use night-time light data and a difference-in-difference approach to investigate the impact of HSR on the expansion of urban areas. They likewise find that HSR development has a positive effect on urban land expansion and that growth effects are stronger in central and western regions. Additionally, they find stronger effects on small and medium size cities than large cities.

All in all, despite broad discussions about the effects of HSR investment on various aspects of urban development, there is little systematic research specifically investigating the causal impact of HSR on urban land growth. Among the few recent works discussed in last paragraph, none have explicitly addressed the endogeneity issues associated with HSR development. It should be recognized that HSR route planning is never an exogenous random decision; it is clearly influenced by the economic growth of cities *en route*. The central government prioritizes certain regions to build HSR because they have already been experiencing rapid growth. Then how much additional land growth is actually induced by the HSR connection? The existing literature as yet fails to provide a clear answer to this question. This paper aims to address the gap.

3. Methodology

3.1 Sample selection

In July 2011, two high-speed trains collided and derailed each other in an incident known as the Wenzhou train crash. As a direct consequence of the accident, HSR network construction in China experienced a national slowdown: a large number of HSR projects were swiftly halted after the accident, and for nearly one year after the collision, no new HSR projects were completed (Shaw et al., 2014). By June 2012, a one-year gap had emerged between cities already connected to the HSR network at the time of the Wenzhou crash and those that had not yet been. Thus, this accident acts as an exogenous disruptive shock that allows us to estimate the impact of HSR on land growth. We use a dummy variable to measure whether or not a city was already connected to HSR by 2012.

Our sample includes cities at the prefecture-level or above. Beijing, Tianjin, Shanghai, Chongqing, Shenzhen, Ningbo, Qingdao, Dalian and Xiamen are excluded, as these cities are municipalities with independent planning status economically and institutionally. In order to ensure that the HSR-linked and non-HSR-linked cities compared otherwise have similar characteristics, this study also excludes cities in non-HSR-linked provinces, as shown in Figure 1. Construction of the Beijing-Tianjin intercity railway—the first HSR in China—began in 2005. Therefore, we choose 2004, when there was as yet no HSR in operation, as the base year for this study. The ending year of this study is 2015. Because the planning process for adjustments of urban built-up district boundaries needs to be approved by provincial governments or even the central government and the process often involves multiple phases, it takes several years for the impact of HSR to fully mature. The exogenous shock (i.e. Wenzhou crash) happened in July 2011 and there were no HSR projects completed in the following 12 months. Therefore, using 2015 as the ending year for this research ensures that the impacts of HSR projects built prior to July 2011 have materialized, while the impacts of those built from 2013 onwards have yet to mature.

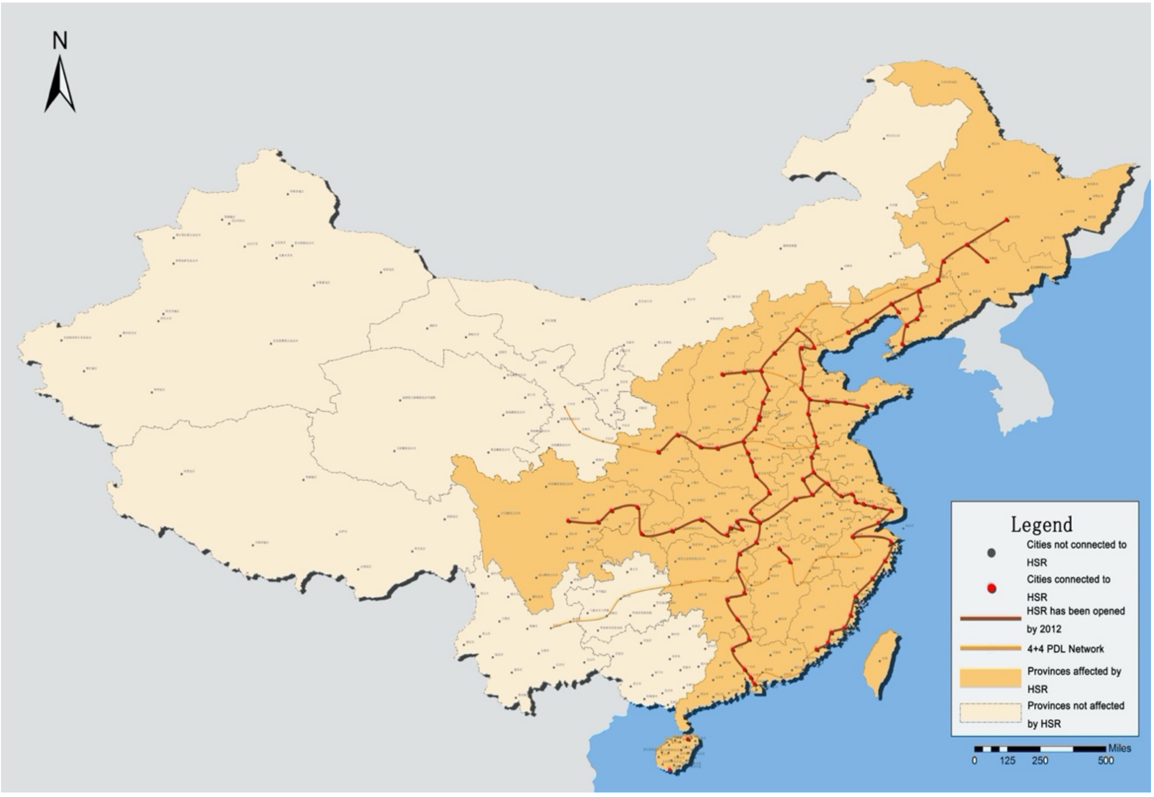

Figure 1 Cities Connected to HSR Network by 2012 and the Study Area (HSR-impacted area)

We use China Statistical Yearbook (CSY) data on the area (in squared kilometres) of built-up districts as our measure of cities' urban built-up land area. According to CSY definition, the built-up area refers to the portion in the urban administrative area that has actually been developed and constructed, and has been equipped with municipal public facilities and infrastructure.

3.2 Model specification and variables

To understand the influence of HSR on urban land growth, this research utilizes a two-period panel data model with city-fixed effects (Wooldridge 2016, p459). The baseline model is shown as equation (1):

$$log(land_{it}) = \alpha + \delta hsr_i + \gamma period_t + \beta_1 log(gdp_{it}) + \beta_2 log(pop_{it}) + \beta_3 X_{it} + \upsilon_i + \varepsilon_{it}$$

where *i* and *t* denote the city *i* and the year *t*, respectively; δ, γ, and β are coefficients for the explanatory variables; and α is the constant term. Dependent variable *land* represents the urban built-up area of city *i* from the initial period to the period *t*; *hsr* is a dummy variable constructed to measure whether or not the city had been connected to the HSR network prior to 2012 (*hsr*=1 meaning the city had HSR before 2012; otherwise, *hsr*=0); and *period* is a temporal dummy variable used to distinguish observations at different time periods (*period*=1 when the year is 2015; otherwise, *period*=0). Several studies have suggested that population and level of economic development are two core factors that affect the rate of land development (Wu & Yeh, 1997; Hu & Lo, 2007; Demirel et al., 2008; Müller et al., 2010; Mothorpe et al., 2013). This research therefore incorporates *gdp* and *pop* into the model, representing a city’s GDP and non-agricultural population respectively. X_{it} is a vector of control variables that may affect land development in city *i at period t*, including general budget expenditure, fixed-asset investments, loan balance of financial institutions, number of hospital beds, domestic consumption of water, and passenger volume of public transportation. υ_i is the time-invariant city-fixed effect, representing all unobservable factors at the city level that affect land development but do not change over time. ε_i is the idiosyncratic error, which represents the unobservable factors that affect land development and change over time.

If the model were to directly adopt pooled OLS regression, heterogeneity bias could result due to composite error (Wooldridge, 2016). Therefore, our study employs the following two-period model for land development:

$$log(land_{i2004}) = \alpha + \beta_1 log(gdp_{i2004}) + \beta_2 log(pop_{i2004}) + \beta_3 X_{i2004} + \upsilon_i + \varepsilon_{i2004} \quad \text{......................(2)}$$

$$log(land_{i2015}) = \alpha + \gamma + \delta hsr_i + \beta_1 log(gdp_{i2015}) + \beta_2 log(pop_{i2015}) + \beta_3 X_{i2015} + \upsilon_i + \varepsilon_{i2015} \quad \text{....................(3)}$$

By subtracting equation (2) from equation (3), we obtain a first-difference equation:

$$\Delta log(land_i) = \gamma + \delta hsr_i + \beta_1 \Delta log(gdp_i) + \beta_2 \Delta log(pop_i) + \beta_3 \Delta X_i + \Delta\varepsilon_i \quad \text{.....(4)}$$

where Δ denotes the change from 2004 to 2015. Equation (4) is a single cross-sectional equation with all variables differenced over time (Wooldridge, 2015). The marginal effect of high-speed rail on land development is given by exp $(\hat{\delta}) - 1$, meaning the 2004-2015 growth rate of urban built-up areas in cities with HSR access is on average 100*[exp $(\hat{\delta})-1$]% faster (or slower) than that in cities without HSR access.[i] Summary statistics for all variables are presented in Table 1.

Table 1 Summary statistics of variables in 2004 and 2015

Year	Variable	Obs	Mean	Std. Dev.	Min	Max
2004	Built-up land area in municipal administrative districts (km^2)	284	84.03	120.86	5	1182
	Year-end total population (in 10,000 persons)	284	123.14	148.58	14.35	1289.13
	Local gross domestic product (in 100 million yuan)	284	322.53	670.56	9.83	7370
	Local government expenditure (in 100 million yuan)	284	34.01	105.8216	1.86	1370
	Balance of RMB loans in financial institutions (in 100 million yuan)	284	634.55	2060	20.67	23600
	Investment in fixed assets (excluding rural areas) (100 million yuan)	284	147.73	301.41	2.72	3080
	Annual volume of water supply (in 10,000 tons)	284	15038.83	29219.21	150	323454
	Number of passengers transported by bus and trolley in a year (in 10,000 passengers)	283	15697.91	44024.54	6	453223
2015	Built-up land area in municipal administrative districts (km^2)	280	146.25	185.86	14	1401
	Year-end total population (in 10,000 persons)	284	156.14	202.96	15.36	2129.09

	Local gross domestic product (in 100 million yuan)	284	1510	3050	30.17	24800
	Local government expenditure (in 100 million yuan)	284	234.69	593.91	10.78	6030
	Balance of RMB loans in financial institutions (in 100 million yuan)	284	2410	5950	83.98	53400
	Investment in fixed assets (excluding rural areas) (100 million yuan)	284	973.47	1520	52.4	13000
	Annual volume of water supply (in 10,000 tons)	284	17204.57	32915.97	481	304440
	Number of passengers transported by bus and trolley in a year (in 10,000 passengers)	283	22863.71	44732.26	81	406003

Note: Sample excludes cities of provinces without high-speed rail or municipalities with independent planning status.

3.3 Instrumental variables to address endogeneity

While HSR may have a significant impact on land development, HSR route planning is also influenced by national development plans and prioritizes reaching cities and regions that experience rapid growth in population, land, and economy. Moreover, faster growing regions can provide more resources to facilitate the completion of high-speed rail projects as the costs of building HSR stations are usually shared between central and local governments. HSR access may therefore be an endogenous variable. In order to accurately estimate the impact of HSR on urban land development, we need to find suitable instrumental variables to address the endogeneity. An ideal instrumental variable should be able to explain the likelihood of HSR construction in different cities, but should not directly affect urban land growth. Note that the instrumental variable is still valid if it indirectly affects land growth through the mechanism of HSR construction.

In this study, we use the post road network in the Ming Dynasty (1368-1644) as an instrumental variable to address the endogeneity problem.[1] First, the choice of location for ancient post roads bears a close relationship to the choice of location for modern HSR lines. Choice of

[1] Source from: https://m.91ddcc.com/t/60853

location for a post road was likely a joint outcome of favourable topography, geology and climatic conditions, which are also ideal foundations for the construction of a HSR line. Second, the presence of an ancient post road is not directly related to modern urban development. Ancient post roads were designed to facilitate cargo and information delivery; the locations of the post road network were therefore closely related to city sizes and economic development levels in ancient times. Yet patterns of development are clearly different in contemporary China after five centuries of change, except for a few major capital cities, suggesting that there is no direct relationship between the ancient post road network and modern urban development. Furthermore, as tributes transported via ancient post roads went directly from foreign countries to the Ming Dynasty court, they did not create beneficial externalities for cities along the line. In sum, the Ming Dynasty post road network has no *direct* impact on modern urban development while it bears close relation to the choice of location for modern HSR lines, making it a plausible instrumental variable to address the endogeneity problem associated with cities' HSR access.

In addition to the Ming Dynasty post road network, this paper uses the locations of military bases in 2005 as a second instrumental variable. This variable has been tested in other research (see Zheng and Kahn 2013). One of the primary purposes of railways in China was to ensure the smooth transportation of military forces and supplies to and between military bases. Hence, the locations of military bases are likely to impact modern HSR planning decisions. At the same time, the presence of military bases has no explicit relationship with economic development levels of specific cities, due to the high mobility of modern troops. Therefore, the presence of military bases provides another good candidate for an instrumental variable. To validate the relevance and proper identification of these two instruments, we adopt a series of statistical tests including DWH test , Partial R-squared, Wald F statistics and Sargan test, as commonly used in other Instrumental Variable (IV) models (e.g., Zhu 2012, 2013; Zhu et al. 2018).

4. Results

4.1 Full sample

Table 2 presents the OLS and IV estimations of the effect of HSR access on urban built-up area growth. The dependent variable is the log difference of the built-up area of a city between 2004 and 2015. All models indicate that the presence of an HSR station has a significant positive impact on the growth of the urban built-up area. The OLS model indicates that, everything else being equal, the growth rate of the urban built-up land area is approximately 3.63% (noting that exp(0.0357)-1=0.0363) faster in cities with HSR stations than those without. The explanatory variables are free of multicollinearity as the mean variance inflation factor (VIF) of all variables is 1.52, with the minimum VIF 1.06 and the max 2.45. The model excludes several economic indicators such as foreign direct investment (FDI) due to strong collinearity with other variables.

After addressing endogeneity, the IV-2SLS model (Model 2) indicates a larger difference, with HSR-connected cities growing 11.2% faster on average. As expected, population, GDP and urban water supply are all found to be positively related to urban expansion. Everything else being equal, a 1% increase in population growth rate is correlated with a 0.35% increase in the growth rate of urban built-up land, while a 1% increase in GDP growth rate is associated with a 0.23% increase in land growth rate. A series of statistical tests are also conducted to ensure the validity of the IV-

2SLS model results. First, the DWH test suggests the presence of endogeneity problem in the baseline OLS model. Second, to rule out the problem of invalid or weak instrumental variables, we use Partial R-squared and Wald F statistics to test the relevance of the instrumental variables. The two instrumental variables altogether explain 17.2% of the variation in the first stage model. The Wald F statistic is 22.98, also greater than the empirical benchmark of 10. Last, the Sargan test indicates there is no problem of over-identification in our IV-2SLS model.

It is likely that Model 2 may overestimate the impact of HSR on land development, because it assumes no improved accessibility from air or expressways between 2004 and 2015. To control for potential confounding effects of increased connectivity from these transport modes, we further conduct stepwise models to include expressway access, the presence of airports, and flight frequency. Model 3 adds a dummy variable to indicate whether the city was added to the national expressway network during 2004-2015. We use the end year of our analysis (i.e., 2015) to measure the expressway access change from the base year because the impact of expressway on land development is much smaller in scale compared to that of HSR and usually materializes much faster. Model 4 further controls for changes in air accessibility, as measured by whether the city built an airport during 2004-2012. We choose year 2012 as the cut-off for airport construction to match the intervention year selected for HSR because they both need a relatively long period of time to generate full impact on a city's land development. We also test 2015 as the cut-off year for airports and obtain very similar results. Note that there are only 10 cities which opened airports between 2013 and 2015. In Model 5, we add the 2010-2015 change in annual number of flights departing from each city to further control for changes in air accessibility. We do not have 2004 flight frequency data, but we believe the 2010-2015 annual flight number changes should be quite informative as an additional robustness check to identify any changes in the coefficient estimates. Comparisons across different IV models (i.e., Models 2-5) show very consistent results for all variables. Land development in HSR-connected cities grows 11.2%-12.1% faster than their counterparts, *ceteris paribus*.

Table 2 Effects of HSR connection on urban built-up land growth (full sample)

Growth rate of built-up land area in municipal administrative districts	**Model 1 OLS**	**Model 2 IV-2SLS**	**Model 3 IV-2SLS**	**Model 4 IV-2SLS**	**Model 5 IV-2SLS**
Connected to HSR by 2012 (dummy)	0.0357** (0.0176)	0.106** (0.0436)	0.107** (0.0453)	0.106** (0.0450)	0.114** (0.0503)
Expressway access change 2004-2015 (dummy)			-0.00033 (0.0229)	0.00037 (0.0230)	-0.00158 (0.0229)
Air access change 2004-2012 (airport dummy)				0.0286 (0.0394)	0.0307 (0.0401)
Air access change 2010-2015 (Annual flight frequency change)					-2.0e-06 (1.9e-06)
Year-end total population in municipal districts (Δlog)	0.377*** (0.0878)	0.347*** (0.0728)	0.346*** (0.0738)	0.348*** (0.0735)	0.344*** (0.0742)
Local gross domestic product (Δlog)	0.217** (0.0847)	0.231*** (0.0819)	0.231*** (0.0825)	0.230*** (0.0823)	0.240*** (0.0834)
Local government expenditure (Δlog)	0.0118 (0.0526)	0.0432 (0.0582)	0.0436 (0.0581)	0.0419 (0.0578)	0.0334 (0.0575)
Balance of RMB loans in financial institutions (Δlog)	0.0839 (0.0571)	0.0556 (0.0621)	0.0553 (0.0625)	0.0632 (0.0621)	0.0698 (0.0620)
Investment in fixed assets (excluding rural district) (Δlog)	-0.0189 (0.0547)	-0.0126 (0.0482)	-0.0125 (0.0482)	-0.0106 (0.0482)	-0.0115 (0.0484)
Annual volume of water supply (Δlog)	0.0991*** (0.0381)	0.0950** (0.0420)	0.0949** (0.0423)	0.0928** (0.0423)	0.0996** (0.0428)
Number of passengers transported by bus and trolley in a year (Δlog)	0.0165 (0.0231)	0.0262 (0.0235)	0.0263 (0.0235)	0.0254 (0.0233)	0.0225 (0.0233)
Constant	0.00315 (0.0486)	-0.0482 (0.0582)	-0.0489 (0.0579)	-0.0542 (0.0598)	-0.0532 (0.0601)
VIF	1.52	-	-	-	-
F statistic	10.69***	-	-	-	-
Durbin Wu-Hausman test (p-value)	-	0.0653	0.0681	0.0739	0.0791
Partial R-squared	-	0.1722	0.1631	0.1678	0.1468
Minimum eigenvalue statistic	-	22.9877	21.4449	22.0812	18.7476
Sargan test (p-value)		0.1970	0.1956	0.1814	0.1629
R-squared	0.378	0.334	0.333	0.337	0.331
Observations	231	231	231	231	231

4.2 Large vs. medium-small cities

HSR may have different impacts on land development in cities of different population sizes. Based on the median population of 846,150, we classified cities into two groups—"large cities" and "medium-small cities". Table 3 shows the heterogeneity in the effects of HSR on urban expansion based on this classification. Columns 2 and 4 report the IV-2SLS model estimates. All models also control for improved accessibility from expressway expansion and air transportation, i.e., whether the city was added to the national expressway network during 2004-2015 and whether the city built an airport during 2004-2012. We also conducted a series of tests to verify the validity of our model results. Partial R-squared statistics suggest our instrumental variables are valid and relevant. The Sargan test indicates there is no problem of over-identification. The DWH test gives different results for the two groups. For large cities, the DWH test suggests that HSR is not significantly endogenous; therefore, OLS estimates can be directly adopted. However, for medium-small cities, the DWH test detects significant endogeneity; hence, the IV-2SLS model should be utilized.

Table 3 Heterogeneous effects of HSR connection on urban built-up land growth in cities of different population sizes (large cities = population over 846,150; medium-small cities = population under 846,150)

Growth rate of built-up land area in municipal administrative districts	**Model 1** **Large cities** **OLS**	**Model 2** **Large cities** **IV-2SLS**	**Model 3** **Medium-small cities** **OLS**	**Model 4** **Medium-small cities** **IV-2SLS**	**Model 5** **Medium-small cities** **IV-LIML**
Connected to HSR by 2012 (dummy)	0.00126 (0.0246)	0.0165 (0.0592)	0.0809** (0.0336)	0.207** (0.0844)	0.208** (0.0846)
Expressway access change 2004-2015 (dummy)	-0.0384 (0.0391)	-0.0390 (0.0331)	0.0195 (0.0298)	0.0510 (0.0369)	0.0511 (0.0369)
Air access change 2004-2012 (airport dummy)	-0.0212 (0.0406)	-0.0146 (0.0475)	0.0218 (0.0289)	0.0364 (0.0802)	0.0364 (0.0802)
Year-end total population (Δlog)	0.449*** (0.136)	0.435*** (0.132)	0.341*** (0.110)	0.313*** (0.0969)	0.313*** (0.0970)
Local gross domestic product (Δlog)	0.281** (0.137)	0.283** (0.125)	0.158 (0.117)	0.159 (0.110)	0.159 (0.110)
Local government expenditure (Δlog)	-0.0352 (0.0740)	-0.0268 (0.0855)	0.0670 (0.0684)	0.100 (0.0808)	0.101 (0.0809)
Balance of RMB loans in	-0.0105	-0.0160	0.121	0.0767	0.0765

financial institutions (Δlog)	(0.0919)	(0.0949)	(0.0746)	(0.0863)	(0.0863)
Investment in fixed assets	-0.0122	-0.00851	0.00566	0.00935	0.00936
(excluding rural district) (Δlog)	(0.0779)	(0.0695)	(0.0809)	(0.0677)	(0.0678)
Annual volume of water supply	0.151**	0.152**	0.0571	0.0544	0.0544
(Δlog)	(0.0604)	(0.0678)	(0.0523)	(0.0553)	(0.0553)
Number of passengers transported	-0.0220	-0.0212	0.0502	0.0551	0.0551
by bus and trolley in a year (Δlog)	(0.0232)	(0.0313)	(0.0385)	(0.0337)	(0.0338)
Constant	0.0835	0.0679	-0.0800	-0.123	-0.123
	(0.0710)	(0.0917)	(0.0632)	(0.0777)	(0.0777)
VIF	1.51	-	1.51	-	-
F statistic	9.24***	-	7.03***	-	-
Durbin Wu-Hausman (p-value)	-	0.7791	-	0.0820	-
Partial R-squared	-	0.1526	-	0.1423	0.1423
Minimum eigenvalue statistic	-	9.45295	-	8.46187	8.46187
Sargan (p-value)		0.1282		0.8075	0.8075
R-squared	0.3310	0.3285	0.4671	0.382	0.381
Observations	117	117	114	114	114

While we find HSR has no statistically significant impact on urban built-up land growth for large cities, the IV-2SLS model (model 4) suggests that, for medium-small cities, HSR has a significant positive impact on the growth of urban built-up area. Holding other factors constant (e.g. GDP growth), growth of urban built-up areas is 22% (noting that exp(0.199)-1=0.22) faster in medium-small cities with HSR stations than in those without stations. As expected, GDP and population growth are also shown to have significant positive relationship with urban land expansion in medium-small cities. Everything else being equal, a 1% increase in population growth rate is associated with a 0.27% increase in the growth rate of urban built-up land, while a 1% increase in GDP growth rate is associated with a 0.21% increase in land growth rate. These results indicate that GDP and population growth are important drivers of urban expansion. In addition, public transit ridership, as measured by the number of passengers transported by city bus and trolley bus, is also significantly associated with urban land expansion. That is, the improvement of public transportation may also promote growth of the urban built-up area in medium-sized and small cities.

As a robustness check, we used the LIML estimation method for the medium-small city sample, in addition to the 2SLS estimation. The results of the LIML estimation (in Model 5 of Table 3) are consistent with those of the 2SLS model (Model 4), indicating that our IV-2SLS estimates are reliable.

4.3 Coastal province cities vs. inland province cities

We further test the heterogeneity in the impacts of HSR on urban land expansion for cities in different geographic regions. We divide sample cities into eastern region (i.e., coastal) cities and central or western region (i.e., inland) cities, as these regions have historically had different economic structures, urban development levels, population flows (in-migration vs. out-migration), and reliance on rail. Table 4 provides the regression results for the coastal city sample (the first and second columns) and inland city sample (the third and fourth columns). In the coastal city sample, the DWH test result indicates that there is no endogeneity problem. Therefore, the results of the OLS model are unbiased and can be directly utilized. However, results show that HSR is not a significant driver for urban expansion in coastal cities.

For the inland city sample, the DWH test results show that significant endogeneity exists, suggesting the results of the IV-2SLS model should be used. The Sargan test shows that we can reject the over-identification hypothesis. The results shown in Table 4 (column 4) indicate that HSR access significantly accelerates urban expansion in inland province cities. Holding other factors constant (e.g. GDP growth), in the central and western regions of China, cities connected to HSR on average expand 20.2% faster than those without HSR connection. In addition, we found that population and GDP growth are two primary determinants of urban expansion in inland cities. Everything else being equal, a 1% increase in population growth rate is correlated with a 0.31% increase in the growth rate of urban built-up land, while a 1% increase in GDP growth rate is associated with a 0.26% increase in land growth rate.

Table 4 Heterogeneous effects of HSR connection on urban built-up land growth in cities located in different regions of China (coastal province and inland province cities)

Growth rate of built-up land area in municipal administrative districts	**Model 1 Coastal cities OLS**	**Model 2 Coastal cities IV-2SLS**	**Model 3 Inland cities OLS**	**Model 4 Inland cities IV-2SLS**
Connected to HSR by 2012 (dummy)	0.0389 (0.0336)	0.0472 (0.0818)	0.0380* (0.0223)	0.190*** (0.0644)
Expressway access change 2004-2015 (dummy)	0.0245 (0.0789)	0.0295 (0.0741)	-0.00872 (0.0242)	0.00224 (0.0261)
Air access change 2004-2012 (airport dummy)	-0.0107 (0.0562)	-0.00752 (0.0621)	0.0239 (0.0300)	0.0527 (0.0597)
Year-end total population (Δlog)	0.299* (0.170)	0.299** (0.129)	0.366*** (0.107)	0.306*** (0.103)
Local gross domestic product (Δlog)	0.291 (0.189)	0.291* (0.163)	0.206** (0.0891)	0.262** (0.108)
Local government expenditures (Δlog)	0.0915 (0.0776)	0.0974 (0.112)	-0.0355 (0.0722)	-0.0327 (0.0769)
Balance of RMB loans in financial institutions (Δlog)	-0.0058 (0.127)	-0.0078 (0.117)	0.119* (0.0657)	0.0644 (0.0820)
Investment in fixed assets (excluding rural district) (Δlog)	0.0110 (0.109)	0.0116 (0.0867)	-0.0170 (0.0646)	-0.0463 (0.0708)
Annual volume of water supply (Δlog)	0.0754 (0.0962)	0.0735 (0.0954)	0.0947** (0.0392)	0.101** (0.0505)
Number of passengers transported by bus and trolley in a year (Δlog)	0.0261 (0.0527)	0.0284 (0.0592)	0.0109 (0.0278)	0.0207 (0.0267)
Constant	-0.0691 (0.0806)	-0.0788 (0.126)	0.0323 (0.0766)	0.00832 (0.0814)
Mean VIF	1.77	-	1.41	-
F statistic	4.20***	-	7.81***	-
Durbin Wu-Hausman (p-value)	-	0.9118	-	0.0030
Partial R-squared	-	0.1562	-	0.1571
Minimum eigenvalue statistic	-	7.21751	-	12.0188
Sargan (p-value)		0.2407		0.3386
R-squared	0.376	0.375	0.371	0.161
Observations	90	90	141	141

4.4 Robustness check

As discussed in our conceptual framework, HSR reduces travel time between cities, increases access to labor and markets, and enhances knowledge spillover. Therefore, as a robustness check to validate our previous model results, we replace the HSR dummy variable (i.e., whether the city is connected to HSR) with the concept "market potential" (MP), first proposed in Harris (1954), to better capture the improvements in accessibility or connectivity induced by HSR. Market potential is usually defined as a city's access to regional markets for goods, services, and labor, weighted by inter-city travel time (Hanson 2005). In this paper, we calculate a city's MP as the travel-time-weighted sum of purchasing power of all nearby cities that can be reached via train (regular or high-speed) within 60 minutes. This measure excludes any improvements in accessibility due to new expressway or airport construction, and hence ensures the calculated MP changes are induced by HSR development. The formula for the MP of city *i* in year *t* is:

$$MP_{i,t} = \sum_{j|T_{ij,t} < 60} P\_Power_{j,t} \cdot e^{-\alpha \cdot T_{ij,t}} = \sum_{j|T_{ij,t} < 60} Pop_{j,t} \cdot Inc\_pc_{j,t} \cdot e^{-\alpha \cdot T_{ij,t}}$$

where $P\text{-}Power_{j,t}$ is the purchasing power of city *j* in year *t* (t=2004 or 2015), calculated as the product of population, $Pop_{j,t}$, and median per capita income, $Inc\_pc_{j,t}$, of city *j* in year *t*. $T_{ij,t}$ is the travel time via train between cities i and j at time t. α refers to the spatially-weighted decay rate of influence between cities i and j. We set α to be 0.02, based on the range of decay rate estimates from similarly defined MP equations in the literature (Hanson 2005; Ahlfeldt and Feddersen 2018; Zheng and Kahn 2013). We also test α=0.01 and α=0.03 and the results are consistent. HSR-induced market potential change for city i from 2004 to 2015 is therefore calculated as the log difference of $MP_{i,2015}$ and $MP_{i,2004}$. As shown in Table 5, after replacing the HSR dummy variable with the HSR-induced market potential change indicator, the impacts of HSR on land development in the full sample and subsamples are all consistent with previous results in Tables

2-4. Note that the sizes of its coefficient estimates are quite different from previous models, because they refer to the marginal effects of HSR-induced market potential change (i.e., travel-time-weighted purchasing power), and hence have different interpretations compared to using the HSR dummy.

Table 5 Effects of HSR connection on urban built-up land growth, using market potential variable

Growth rate of built-up land area in municipal administrative districts	**Model 1 Full sample IV-2SLS**	**Model 2 Large cities IV-2SLS**	**Model 3 Medium-small cities IV-2SLS**	**Model 4 Coastal cities IV-2SLS**	**Model 5 Inland cities IV-2SLS**
HSR-induced market potential change (Δlog)	0.0273**	-0.00273	0.0461**	0.00997	0.0477***
	(0.0127)	(0.0158)	(0.0216)	(0.0267)	(0.0173)
Expressway access change 2004-2015 (dummy)	-0.000821	-0.0372	0.0546	0.0229	-0.00272
	(0.0240)	(0.0336)	(0.0411)	(0.0845)	(0.0272)
Air access change 2004-2012 (airport dummy)	0.0343	-0.0270	0.0469	-0.0112	0.0705
	(0.0423)	(0.0503)	(0.0846)	(0.0684)	(0.0643)
Year-end total population (Δlog)	0.347***	0.462***	0.329***	0.278**	0.386***
	(0.0766)	(0.140)	(0.100)	(0.140)	(0.105)
Local gross domestic product (Δlog)	0.241***	0.278**	0.166	0.304*	0.270**
	(0.0861)	(0.126)	(0.115)	(0.174)	(0.114)
Local government expenditures (Δlog)	0.0162	-0.0347	0.121	0.0753	-0.0795
	(0.0580)	(0.0795)	(0.0893)	(0.106)	(0.0822)
Balance of RMB loans in financial institutions (Δlog)	0.0824	-0.0136	0.0541	0.00436	0.107
	(0.0634)	(0.0948)	(0.0967)	(0.119)	(0.0831)
Investment in fixed assets (excluding rural district) (Δlog)	-0.0281	-0.0132	-0.0251	0.0110	-0.109
	(0.0501)	(0.0682)	(0.0722)	(0.0892)	(0.0815)
Annual volume of water supply (Δlog)	0.101**	0.150**	0.0592	0.0735	0.131**
	(0.0440)	(0.0682)	(0.0577)	(0.0992)	(0.0547)
Number of passengers transported by bus and trolley in a year (Δlog)	0.0291	-0.0224	0.0631*	0.0323	0.0231
	(0.0248)	(0.0312)	(0.0358)	(0.0675)	(0.0281)
Constant	-0.0539	0.0947	-0.132	-0.0756	0.0468
	(0.0631)	(0.0897)	(0.0842)	(0.160)	(0.0847)
Durbin Wu-Hausman (p-value)	0.058	0.7834	0.0758	0.7214	0.005
Partial R-squared	0.0969	0.0853	0.1118	0.0652	0.1025
Minimum eigenvalue statistic	11.699	4.89601	6.35688	2.68362	7.36649
Sargan (p-value)	0.1568	0.1248	0.3295	0.2467	0.2978
R-squared	0.285	0.327	0.331	0.352	0.076
Observations	230	117	113	89	141

5. Discussion

The relationship between HSR and urban land development is tied to the concept of accessibility. With the development of this faster mode of transportation, growth in newly connected regions is stimulated by lower transportation costs and greater access to labour, capital, and markets. This stimulates more social-economic activities in these regions. As the manufacturing and service sectors continue to expand, it is expected that more urban land will be developed to support production and meet expanding demand. One might expect this impact to be significant for all types of cities. However, the empirical evidence suggests otherwise. Our analyses show that HSR connection leads to significantly faster expansion of urban built-up area in small cities or cities in inland provinces, but not in large cities or coastal province cities. This is consistent with findings in Long et al. (2018) and Zhu et al. (2020).

There are multiple potential explanations for these heterogenous impacts. The impact of HSR in smaller cities may be more of a step change in connectivity, and therefore have a stronger effect on stimulating land development.[2] However, examining the roles and incentives of governments suggests there may be more influential factors leading to this disparity. Fundamentally, land development in many countries is not entirely controlled by demand and the 'invisible hand', especially in China, where state ownership of land puts control over land supply exclusively in the hands of governments rather than the private market, resulting in a unique top-down development model in which municipal governments play a central role in the process of urban planning and construction. To understand whether and to what extent HSR connection leads to urban land growth in China, we further discuss two main drivers that are connected with governments' roles and incentives: 1) the bargaining power of local governments in determining HSR station location; and 2) the extent of local governments' reliance on land-based fiscal revenue and local officials'

[2] Our robustness check using market potential, shown in Model 3 in Table 5, actually corroborates this.

political entrepreneurism. Although these factors may be specific to China's institutional context, all governments play a role in urban planning to a greater or lesser extent, and understanding how the power of local government can shape how urban morphology respond to HSR development has implications for other countries developing HSR systems.

5.1 Local government bargaining power and its impact on HSR development

Municipal governments and the Ministry of Railways (MOR) are both major players in the process of HSR planning and construction. For municipal governments, HSR-driven new town development should ideally mesh with the existing urban spatial structure, promoting rational urban development. Meanwhile, for MOR (or later the National Railway Administration), HSR tracks should ideally be designed in a straight line in order to maintain high operating speeds and to reduce travel time between a few major cities (Zeng and Wu, 2004). Site selection for HSR stations is the outcome of negotiations and comprise between municipal governments and MOR, and the results depend on the relative bargaining power of different municipal governments (Zhu et al. 2015).

Depending on their development model, cities may prefer to renovate their old railway system and locate their HSR station in developed urban areas, or they may prefer to build new HSR stations in the urban periphery in order to reduce costs. Upgrading old stations leverages the positive effects of enhanced access to the urban core but is also costly due to the need to clear existing commercial and residential areas. This model has been adopted in Japan and European countries. For example, Japan has designed many of its Shinkansen lines to run directly through urban areas. In European countries with lower population density, downtown to downtown high-speed rail has also been a common choice. However, in a country like China, characterized by rapid urbanization and dense population, routing HSR lines through existing urban areas may not be the optimal choice. By taking advantage of the expansive and relatively inexpensive land resources in the suburbs, municipal governments not only reduce the land acquisition costs associated with HSR construction but may also benefit from land appreciation in the vicinity of the HSR station. In fact, the vast majority of China's high-speed rail stations are built on the edges or in the outer suburbs of cities, where land resources are cheap and abundant. Only in a few cases, when old stations have been renovated to accommodate high-speed trains, is the phenomenon of high-speed rail running through the city observed.

Regardless of a municipal government's preference, how much influence it has over site selection depends on its bargaining power. As Zhu et al. (2015) point out, cities of different economic status possess different bargaining chips to negotiate with the Ministry of Railways. Due to their higher GDPs, large cities or cities in coastal provinces tend to have more power to negotiate for site selections that promote suitable urban development. Many large or coastal province cities have used the introduction of HSR as an opportunity to accelerate their urban spatial restructuring—to redistribute and optimize the location of multiple function areas and possibly shift from a monocentric to a polycentric urban structure. Meanwhile, small cities or cities in inland provinces, with their small economic impact and population size, are more disadvantaged in negotiations with the Ministry of Railways. As a consequence, HSR stations in many of those cities are located tens of kilometres from existing urban areas to accommodate the already planned line. This results in excessive spatial growth of the city in the form of 'strip development' to quickly fill the land between the existing urban area and the new HSR station area (often planned as an HSR new town), or sometimes even leads to leapfrog development where the new town is completely separated from the city. Therefore, the lower bargaining power of small cities or inland provinces cities relative to large cities or coastal province cities also offers a potential explanation for stronger effect of HSR on urban land expansion in smaller and inland province cities.

5.2 Political entrepreneurism and HSR new town development: a race to increase local land-based fiscal revenue

Another factor potentially affecting the amount of urban land growth due to HSR connection may be local governments' different levels of dependence on land-based fiscal revenue. Effective from January 1, 1994, the State Council of China implemented the Tax Division Management System to reform the distribution of tax revenues between central government and local governments. Since then, the central government has implemented a series of fiscal decentralization and land reform policies to stimulate economic growth at the local level. This gradual shift of fiscal authority has granted more freedom to local governments to mobilize capital and plan for urban infrastructure (Huang & Chan, 2018). Yet as the central government gradually eliminated direct grants to finance local development, fiscal decentralization also created considerable financial burdens and challenges for municipal governments.

Facing the challenge of promoting economic development on relatively limited fiscal budgets, municipal governments are pressured to exhaust all available approaches to expand their tax base and increase their fiscal revenue. Among them, land-based fiscal policy (*a.k.a.* 'tudicaizheng' in Chinese) is a popular solution. In China, municipal governments represent the central government and possess legal title to urban land, while rural land is collectively owned by all members of each village (Jiang et al. 2017; Zhu, 2016; Zhu et al., 2017). Through large-scale land development, municipal governments can expropriate rural land from villages, alter the land use designation to 'urban' land, and then sell or rent it in the land market, thus generating a considerable amount of land conveyance revenue, urban land use tax and land value increment tax (Wang et al.,2017).These revenues and taxes are classified as off-budgetary income based on the Tax Division Management System and hence can be completely retained by municipal governments (Wei & Zhao, 2008). Indeed, land-based fiscal policy underlies the unique structure of fiscal accumulation in Chinese cities and incentivizes municipal governments to facilitate large-scale land development. Several case studies have found evidence that institutions embedded in land finance are contributing to urban expansion and even urban sprawl in many cities of China (Pan et al., 2015; Wu et al., 2015; Chen and Haynes, 2015).

Furthermore, GDP growth is an important factor for local government officials' (e.g., the mayor and deputy mayor) promotion prospects in China when their political achievements or performances are evaluated by the central government (Wu et al., 2013). Local officials have become increasingly entrepreneurial as they seek to gain political benefits in return for facilitating economic growth. We refer this as *political entrepreneurism*.[3] As land-based fiscal revenue has become a critical income source for local governments to invest in other industries or sectors, local officials are enthusiastic about any possible means to induce large-scale land development, promote local economic growth and hence improve their political career prospects.

[3] *Political entrepreneurism* is a term we developed from the terms of political entrepreneur or political entrepreneurship (see for example, Mccaffrey & Salerno 2011). It resembles the concept of market entrepreneurism and extends entrepreneurial economics theory from explaining economic behavior to political behavior.

Planning and developing HSR new towns clearly serves this end as such developments allow municipal governments to leverage and magnify the potential of land-based fiscal policy. By proactively planning the construction of urban public facilities and infrastructure like HSR stations, municipal governments can drive up the price of land and real estate in the surrounding areas. Leveraging the expectation that HSR new towns will foster new sources of economic growth in the city, local governments are able to capture additional fiscal revenues from land conveyance and land-related taxation. Moreover, building new train stations and HSR new towns away from the existing city centers also enables municipal governments to design the entire surrounding areas into a modern setting, thereby enhancing the city's image to attract investment and providing a monument to local officials' political achievements.

As small cities and cities in inland provinces are more economically volatile in terms of both economic structure and capacity, their municipal governments tend to be more dependent on land-based fiscal revenue than the governments of larger or coastal cities. Land development in HSR new towns could thus be an important strategy to increase off-budgetary income, hence heavily promoted by such municipal governments. This may be another reason that high-speed rail provokes faster land growth in small cities and inland province cities.

5.3 Case Studies

To better understand the causal mechanisms driving different rates of urban expansion, we use two cities as cases studies to further illustrate how HSR access may influence land development outcomes and associated spatial structure changes in different types of cities. Nanjing, the capital city of Jiangsu Province, is located in the developed coastal region of China. It had a population of

5.01 million in 2004 and 6.51 million in 2015. The city's long efforts in its negotiation with the Ministry of Railways (MOR) about its new HSR station plan have been well documented. Records shows that, on June 13, 2003, the Ministry of Railways 'suddenly' convened a meeting with Nanjing municipal government to notify the city that MOR had finally decided to give up its preferred scheme, which had previously planned to place the new HSR station north of the city. After years of negotiations and persistence, Nanjing eventually persuaded the MOR to accept its own proposal to locate the new HSR station in its southern district. Even after this, the city had to go through many rounds of discussions, debates, and negotiations with the MOR on other details about the design and planning of the station and its adjacent area (e.g., total underground space area, site selection for the South Inter-city Bus Terminal). Between 2006 to 2008, the Nanjing City Planning Bureau literally sent representatives to Beijing "at least once each month" to "fight for the city's interests".[4] Eventually, the Nanjing South Railway Station Design Plan was finalized in August 2008, seven months after construction began. As shown in Figure 2a, most land near the planned HSR station was already built in 2004. Comparing 2015 (Figure 2b) to 2004 (Figure 2a), the net increase in built-up land area in the city's southern district was moderate. Although Nanjing's HSR New Town, officially named the "South New City", was planned to cover a land area of 184 km^2 with 1.6 million people, the majority of the 'new city' had already been built prior to 2004. With this strategically selected location for its new HSR station, Nanjing was able to promote intensive and efficient land use in its South New City, create a new economic center to improve the existing polycentric urban spatial structure, and fuel sustainable economic growth.

[4] https://web.archive.org/web/20110809145458/http://www.js.xinhuanet.com/xin_wen_zhong_xin/2011-06/23/content_23076423.htm

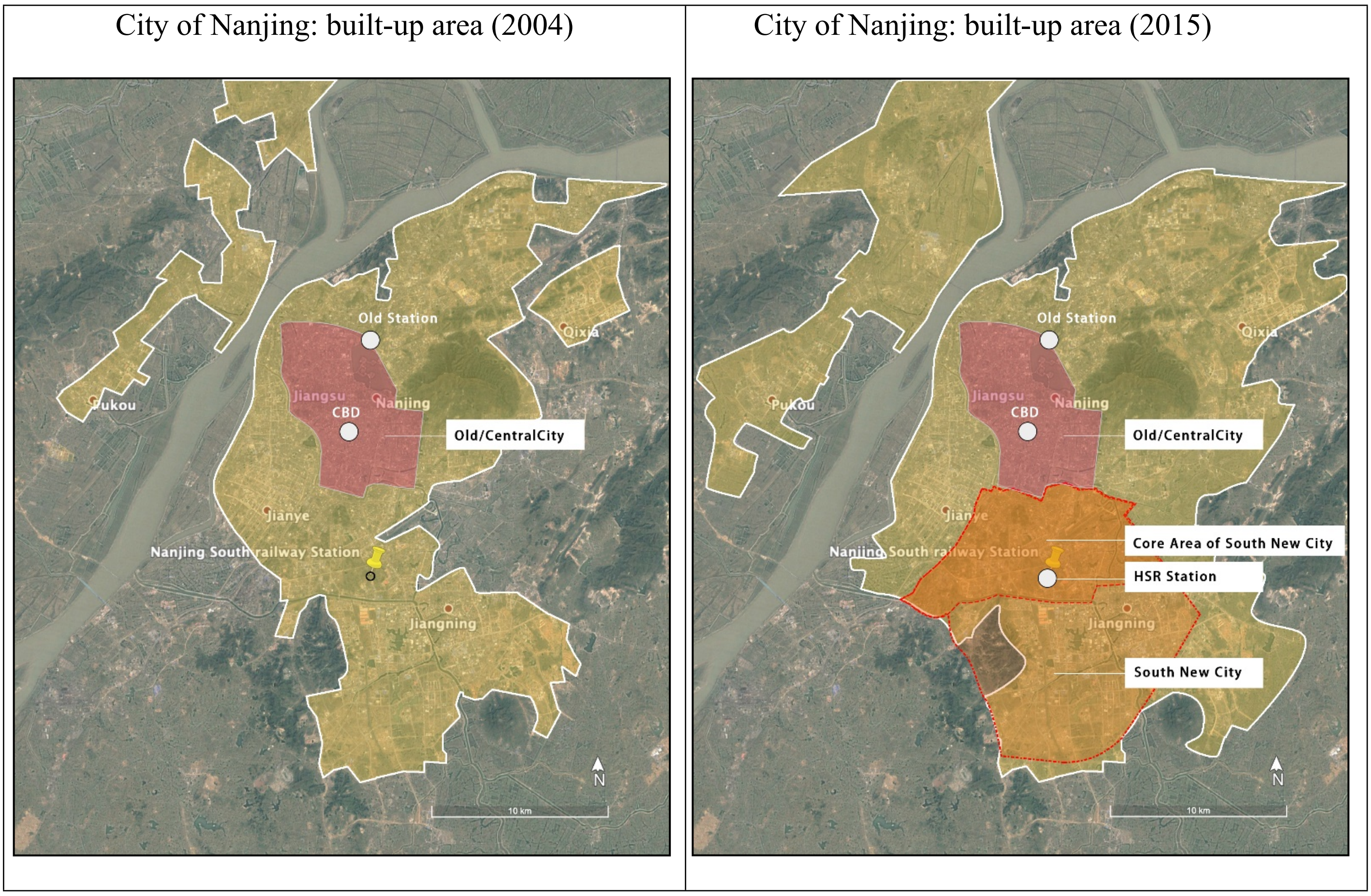

Figure 2 City of Nanjing: Built-up Land Area Change 2004-2015

On the other hand, Hebi is a small-size prefecture-level city in the inland province of Henan. It consists of three districts: Heshan, Shancheng, Qibing. Heshan and Shancheng districts are old mining towns where most mining-related industries are located. In 1992, Qibin district was newly established as an economic development zone. In 1999, the Hebi Municipal Government and its associated administrative offices relocated from Shancheng District to Qibin District. The location for Hebi's HSR station was determined by MOR in 2009, with no documented negotiations between the city and MOR. Fortunately, the station was just a few kilometers south of the Qibin District, because the planned Beijing-Guangzhou HSR line would pass right through the eastern edge of the district. By 2015, Hebi's Qibin District clearly exhibits a strip development pattern, extending from its old district center southward. From 2004 to 2015, Hebi's land-based fiscal revenue increased from 0.127 billion to 2.118 billion CNY, representing a share of total fiscal revenue that skyrocketed from 22.1% to 63.3%. By comparison, the share of land-based fiscal revenue with respect to total fiscal revenue in Nanjing only increased from 18.8% to 43.1% during the same period. The city of Hebi successfully leveraged HSR as a major strategy to spur land development and increase off-budgetary income.

However, land use efficiency and population density in the new district have both been quite low. Most buildings are 5-6 stories high and there is a significant amount of vacant land. An article published in *Sina Finance* in 2013 commented that Qibin District's Master Plan looks like "a long strip extending from north to south", a "very awkward" spatial pattern given that the major industries of the city are mostly located in the two old districts 40 kilometers to the northwest.[5] Hebi's economy is dominated by the secondary industry. Its tertiary industry is very weak and mostly real estate-related. In 2013, the secondary industry accounted for 71.1% of Hebi's GDP and the tertiary industry only 18.5%. There are very few manufacturing jobs in Qibin District, meaning that most residents need to "get up at 5-6am and commute by bus for over an hour to work in the old districts." The rapid land development not only compromises land use efficiency but also causes severe job-housing imbalance and excessively long commutes.

[5] http://finance.sina.com.cn/china/20130223/010414622739.shtml

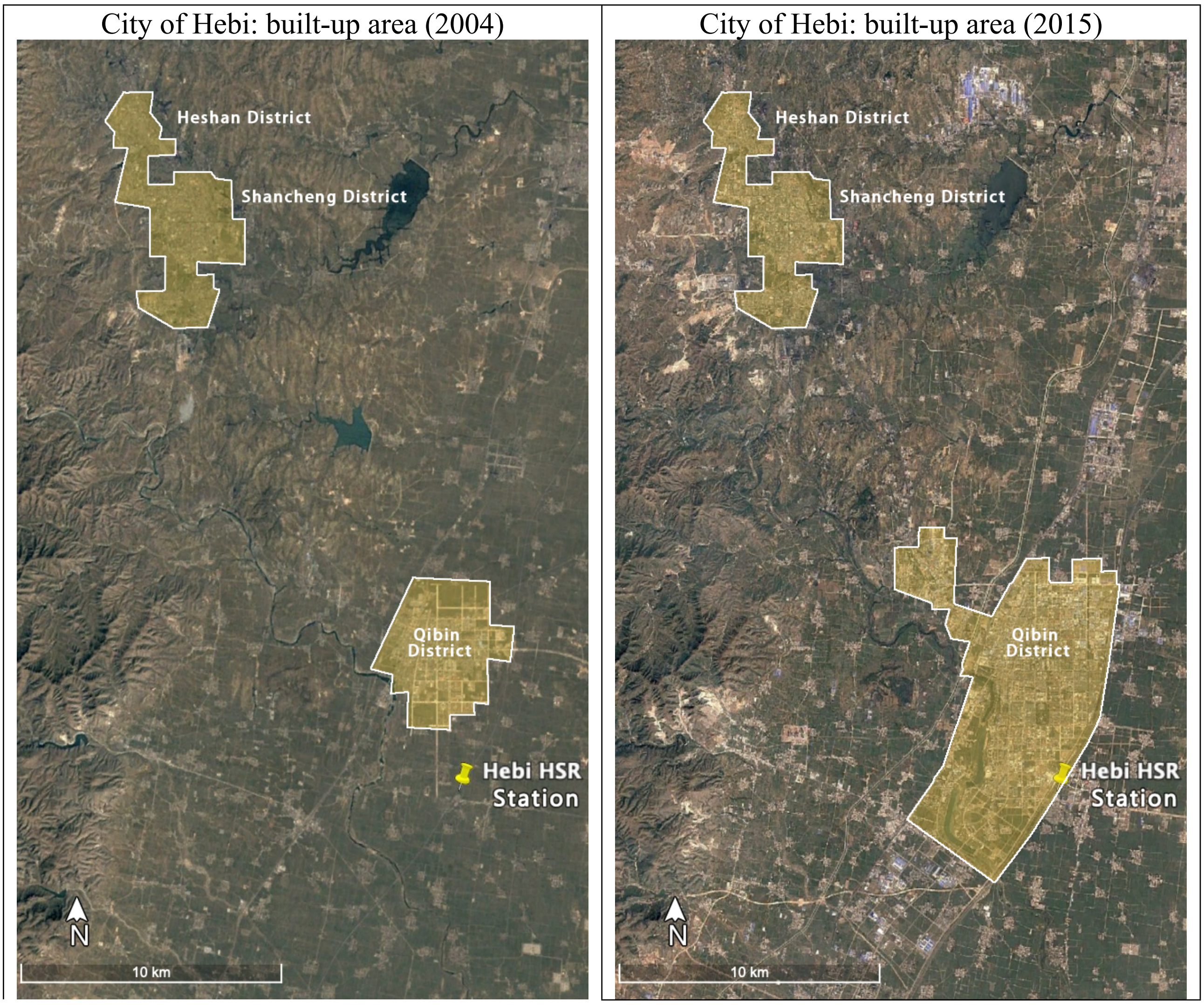

Figure 3 City of Hebi: Built-up Land Area Change 2004-2015

6. Conclusion

Large-scale HSR development in China has significantly improved regional accessibility, stimulating the transformation of hierarchical urban systems at the regional level and urban spatial structure at the municipal level. Meanwhile, municipal governments have often regarded HSR stations as anchors for local development. Local governments invest significant resources into HSR new towns and thereby accelerate the urban land growth triggered by HSR. For policymakers to make rational urban planning decisions and craft effective urban development strategies, it is important to understand the mechanisms and heterogeneity of HSR's impact on urban land growth.

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This study finds that cities with HSR stations tend to witness faster growth of urban built-up areas than cities without HSR stations. This indicates that HSR, as a technological breakthrough in modern transportation, accelerates urban land growth. However, there is obvious heterogeneity in the impact of HSR based on the size and the geographical location of cities. Our findings suggest HSR stimulates urban land growth in small cities and cities of inland provinces, but has little influence on urban land growth in large cities and those of coastal provinces.

Two factors may contribute to this heterogeneity. First, due to their relatively disadvantaged economic status, small and inland cities are less able to negotiate for an HSR station location that meshes with their existing urban spatial structure. This may result in strip development, or even leapfrog development of HSR new towns that are far away from existing urban areas, thus provoking excessive spatial growth. Second, land development in such cities is intensified by municipal governments' reliance on land-based fiscal revenue and local officials' political entrepreneurism. With limited fiscal budgets, these government officials may actively plan and develop land resources in the vicinity of HSR stations in the hope that this will create new engines of economic growth, thereby improving their political career prospects. These two mechanisms may help to explain the high rates of urban land growth associated with HSR construction in small and inland province cities, while being far less significant in large and coastal province cities.

Our findings have several policy implications for decision makers around the world. Theoretical models suggest that the success of employment sub-centers is determined by the level of fixed public capital investment and connections between the central city and the sub-centres (Helsley and Sullivan, 1991). The construction of an HSR new town does not necessarily guarantee economic prosperity. Remotely-located HSR new towns are often unable to generate positive economic externalities due to their weak connections with the existing urban core, especially when efficient public transport connections between the central city and the HSR new town are not available (Wang et al., 2018). This could impede the formation of agglomeration economies in HSR new towns, and instead result in excessive urban land expansion in the form of urban sprawl, waste of municipal resources, and even "ghost towns". Sprawl may furthermore lengthen daily commutes and make public transportation less convenient, hence encouraging reliance on the automobile (Dong and Zhu 2015; Zhu et al., 2013). This would counteract some of the important goals of HSR development—to reduce the use of fossil fuels and enhance environmental sustainability.

To avoid such results, central institutions coordinating overall HSR development should put greater weight on the needs of cities *en route* and increase planning coordination with city governments. Adjusting the location of stations by just a few kilometers could significantly help to integrate HSR-driven development into the existing urban structure and reduce unnecessary sprawl. Meanwhile, local officials and urban planners must make detailed assessments of the feasibility of HSR new town development before they make decisions. Smaller cities with less bargaining power that are not able to negotiate for an optimal HSR station location should plan with care to avoid falling into the "HSR new town trap" and avoid being overly aggressive in their development plans. Whether and when a HSR new town can be planned and constructed should depend on how far away the HSR station is from the existing urbanized area. Until urban development has naturally reached the HSR station area, or the urban diseconomies in the existing CBD can justify a second urban center, large-scale development projects around HSR stations should be viewed with caution, as they would otherwise lead to inefficient land use and unsustainable development. Additionally, overly extensive HSR new town projects could potentially become explosive fiscal burdens and trigger a future debt crisis for municipal governments if they fail to generate sufficient fiscal revenue. It is hence important for municipal governments to reasonably allocate their limited resources to balance development in the central city and the HSR new town. In sum, it is critical that policymakers in different cities develop more tailored schemes in line with the local land-use situations and make timely adjustments in their strategies of land development around HSR stations.

Overall, this research offers new insight into the relationship between large-scale transportation infrastructure investment (i.e. HSR) and urban land growth in China. As high-speed rail networks are currently being proposed and designed to extend from Southeast China (the city of Kunming) to Southeast Asian countries such as Thailand, Vietnam, Malaysia, and Singapore, this research will also have important policy implications for transportation planning and urban development in these countries. Moreover, under China's Belt and Road Initiative, many other countries are currently considering HSR development, in the hope of fuelling their own economic growth and promoting environmental sustainability. This research therefore provides timely and important insight on how to take advantage of HSR development to improve land use efficiency and reduce urban sprawl, all of which will have substantive long-term economic and environmental impacts.

Lastly, it is worth noting that there are a few limitations to our approach, which may actually point to new directions for future research. First, while this paper uses the built-up land area provided by CSY as our dependent variable, we acknowledge an increasingly popular alternative is to use land cover data and night-time lights (NTL) data from satellite imagery to study urban growth (see for example, Yang et al. 2019; Liu X. et al. 2020). There are pros and cons associated with census data compared to satellite imagery. Future research can use satellite imagery data to measure land development and apply the same Instrumental Variable models to verify whether the results are consistent with this paper. Second, we did not choose a dynamic Difference-in-Difference model (DID) because the purpose of this research is to identify the causal impact of HSR on land development. For a DID model to be able to identify causal impact, a fundamental assumption is that the treatment assignment needs to be determined by a random exogenous source of variation. However, as we discussed, HSR route planning is never an exogenous random decision. Hence the Two-period Panel Data Instrumental Variable model is a better identification strategy than the dynamic DID model. Nonetheless, one disadvantage associated with such model is the small sample size, which might contribute to the lack of statistical significance of some of the explanatory variables.

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[i] Based on the first-difference equation:

$$\Delta\log(land_i) = \gamma + \delta hsr_i + \beta_1 \Delta\log(gdp_i) + \beta_2 \Delta\log(pop_i) + \beta_3 \Delta X_i + \Delta\varepsilon_i \quad (4)$$

we can derive:

$$\frac{land_{i2015}}{land_{i2004}} = \exp(\gamma + \delta hsr_i + \beta_1 \Delta\log(gdp_i) + \beta_2 \Delta\log(pop_i) + \beta_3 \Delta X_i + \Delta\varepsilon_i) \quad (5)$$

where $land_{i2015}/land_{i2004}$ represents the growth rate of urban built-up land from 2004 to 2015. Extrapolating from equation (5), the impact of high-speed rail on the growth rate of urban built-up land is:

$$\frac{\left(\frac{land_{i2015}}{land_{i2004}}\right)_{hsr=1}}{\left(\frac{land_{i2015}}{land_{i2004}}\right)_{hsr=0}} = \frac{\exp(\gamma + \hat{\delta} hsr_i + \hat{\beta}_1 \Delta\log(gdp_i) + \hat{\beta}_2 \Delta\log(pop_i) + \hat{\beta}_3 \Delta X_i + \Delta\varepsilon_i)_{hsr=1}}{\exp(\gamma + \hat{\beta}_1 \Delta\log(gdp_i) + \hat{\beta}_2 \Delta\log(pop_i) + \hat{\beta}_3 \Delta X_i + \Delta\varepsilon_i)_{hsr=0}}$$

……………. (6)

When all other explanatory variables take their respective means, the expected value of above equation is simply $\exp(\hat{\delta})$. Hence, the marginal effect of high-speed rail on land development is given by $\exp(\hat{\delta})-1$, meaning the (2004-2015) growth rate of urban built-up areas in cities with HSR access is on average 100*[$\exp(\hat{\delta})-1$]% faster (or slower) than that in cities without HSR access.