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Transport network changes and varying socioeconomic effects across China's Yangtze River Delta

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ABSTRACT

Newly constructed transport infrastructure may have varying socioeconomic effects across cities and regions. This study employs a spatial equilibrium model to examine how the development of expressways and high-speed rails (HSRs) may induce changes in employed residents, housing rents, and consumer surplus within China's Yangtze River Delta region. Empirical findings indicate limited effects of transport infrastructure in reducing disparities, when juxtaposed with the substantial and sometimes conflicting impacts of urban development (i.e., job and housing increments) at the regional level. A more detailed spatial analysis suggests that the positive effects towards even development from transport accessibility improvements are more applicable to bridging intra-city-regional disparities. This highlights the necessity for integrated urban development and transportation planning policies to optimise equitable socioeconomic outcomes.

1. Introduction

The development of transport infrastructure has profoundly altered urban landscapes and regional economies across the globe. This evolution has not only reshaped cities and regions but also spurred an increasing interest in understanding the effects of these changes, particularly their distribution across different geographic and socioeconomic dimensions (e.g., Geurs et al., 2009; Meijers et al., 2012; Kasraian et al., 2016). Recent transport-geographical studies have highlighted equity issues (Pereira et al., 2017). Relatedly, researchers analysing the variegated local effects of transport infrastructure have employed different perspectives to capture the full spectrum of impacts, ranging from economic to social aspects (Rietveld, 1994; Lakshmanan et al., 2001; Meijers et al., 2012; Condeço-Melhorado et al., 2014; Bian and Yeh, 2020).

Methodologically, existing studies focus on measuring effects through different indicators of accessibility (López et al., 2008; Meijers et al., 2012; Moyano et al., 2018; Gao et al., 2019; Bian and Yeh, 2020) and associating accessibility changes with spatial distribution of socioeconomic activities (Mohammad et al., 2013; Condeço-Melhorado et al., 2014; Cascetta et al., 2020). Other modelling approaches such as land use-transportation interaction models (Acheampong and Silva, 2015) and general equilibrium framework (Li and Ma, 2021; Piskin et al., 2020) have also been explored. Despite the breadth of insights provided, few studies consider the "supply-demand relationships in multiple urban markets simultaneously" at refined spatial scales, especially focusing on labour and housing market in the same framework (Jin and Yang, 2022, p. 12). While studies have started to examine the varying effects of transport infrastructure across Chinese cities (Bian and Yeh, 2020; Liu and Zhang, 2018; Yu et al., 2013; Yu et al., 2016), empirical results may be inconclusive. Still, more evidence could be accumulated regarding effects beyond changes in economic outputs as well as at multiple geographical scales (Meijers et al., 2012).

In light of these methodological and empirical gaps, this study explores how transport network changes may affect the spatial distribution of employed residents, housing rents and consumer surplus across China's Yangtze River Delta (YRD) region. The analysis is performed based on 307 county-level zones within YRD during the period between 2015 and 2020. Transport network changes and socioeconomic effects are assessed based on different scenarios (Yang, 2020) and at both regional and city levels.

To conduct this multi-factor and multi-scalar analysis, this study extends and applies a spatial equilibrium (SE) model by Jin and Yang (2022). This approach facilitates the capture of the complex interplay

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between transport accessibility, labour markets and housing markets within a unified framework (Anas and Liu, 2007; Jin et al., 2013; Jin and Yang, 2022; Yang, 2020). Empirically, the SE model helps providing empirical evidence on the (spatially) varying effects of transport infrastructure across a rapidly developing region, at different geographical scales, and beyond traditional measures of economic outputs. Methodologically, the SE model can potentially be applied to other contexts for comprehensive assessments of transport infrastructure impacts. Such a model addresses a notable literature gap, which often focuses on either accessibility indicators or specific socioeconomic outcomes, without fully integrating the supply-demand relationships across multiple urban markets.

2. Literature review

Existing studies have pointed to varying effects of transport infrastructure across cities and regions (Jiao et al., 2020; Kasraian et al., 2016; Yu et al., 2016). Transport infrastructure may led to more balanced (spatial) patterns of development, such as growth in peripheral regions (Heuermann and Schmieder, 2019) and reduced gaps in land prices across cities (Li and Chen, 2022). However, in some cases, improved transport infrastructure may be associated with further (spatial) imbalance. For instance, in the US context, Allen and Arkolakis (2022) have observed that highway's impacts on welfare vary across different types of segments. López et al. (2008) further suggest that patterns of accessibility changes may differ between transport modes. In Brazil, Pereira et al. (2019) find transport investments have intensified socio-spatial inequalities in opportunity access. Beyazit (2015) discovers that in Turkey, the metro system investment drove off the low-skilled workforce and exacerbated inequality. Empirical analyses also concern the effects of transport improvements in areas with different levels of accessibility (Meijers et al., 2012; Jedwab and Moradi, 2016; Wang et al., 2022; Baum-Snow et al., 2017; Garcia-López et al., 2015). Furthermore, studies have suggested that improvements in transport infrastructure may assume a "supporting," rather than a dominant one (Banister and Berechman, 2001; Chen et al., 2016; Kim and Yi, 2019; Meijers et al., 2012, p. 189; Bian and Yeh, 2020). Other dimensions, such as investments and expansion of employment and housing, may overshadow the influence of transport factors (Spiekermann and Wegener, 2006; Banister and Berechman, 2001; Banerjee et al., 2020).

The diverse effects of transport development are clearly observable in China (Yu et al., 2016; Bian and Yeh, 2020; Jiao et al., 2020). For instance, Yu et al. (2013) suggest that transport infrastructure generates higher spillover effects in more developed regions, and Yu et al. (2016) argue that the economic benefits from improved accessibility may come at the expense of widening regional disparities. In the YRD context, Wang (2018, p. 34) finds the HSR development increases the relative regional accessibility gap, potentially leading the "peripheralisation of the periphery". Conversely, other research underscores the positive effects of transport infrastructure on the regional economy. For example, Xu et al. (2019, p.83) suggest that HSR within city-regions may be serving secondary districts. Jiao et al. (2024, p.1) also observe that HSR may contribute positively to regional integration in the YRD. Guan et al. (2023) suggest that densely populated but peripheral cities may stand to gain significantly from the introduction of HSR. Furthermore, Ren et al. (2022) confirm the positive effects of both roads and railways on factor markets and regional integration within the YRD agglomeration.

Methodologically, accessibility and changes therein are the common analytical lens through which effects of transport improvements on socioeconomic outcomes are assessed (Calthrop et al., 2010; Meijers et al., 2012; Stepniak and Rosik, 2013; Bian and Yeh, 2020; Cascetta et al., 2020). Specifically, the impacts of transport policy interventions on different localities have often been measured based on changes in economic activities (e.g., Yu et al., 2016) and welfare (e.g., Kim et al., 2011). Multiple pathways between transport and urban development have been highlighted in the literature and could be incorporated into models (de Bok, 2009; Meijers et al., 2012; Rietveld and Bruinsma, 2012; Li and Ma, 2021), including but not limited to (new) equilibrium between labour demand and supply as well as between production and consumption of goods (Targa et al., 2006; de Bok, 2009; Meijers et al., 2012; Hiramatsu, 2018). Commonly employed approaches include land use-transportation interaction models (Acheampong and Silva, 2015) and general equilibrium framework (Li and Ma, 2021; Piskin et al., 2020). Oftentimes, models employ longitudinal data, characterise socioeconomic activities and interactions (e.g., supply and demand), and incorporate transport development through production inputs or/and accessibility (Donaldson and Hornbeck, 2016; Salling and Banister, 2009; Piskin et al., 2020; Jin and Yang, 2022). However, many methods may not fully capture the granular, localised impacts of transport investments and supply-demand dynamics. Recent advances in models have facilitated the analysis of relatively large geographical areas at refined scales focusing on labour and housing markets (Jin and Yang, 2022).

3. Methodology

3.1. Study area

This study focuses on China's YRD region (Fig. 1), which has undergone rapid growth and significant transport infrastructure investments (Liu et al., 2020; Pan et al., 2020). Based on information from individual provincial statistics bureaux, the population in this region increased from 1.9 billion in 2000 to 2.4 billion in 2020. From 2015 to 2020, the expressway mileage increased from 13,400 to 15,700 km. In terms of HSR, starting from a baseline of 3250 km in 2015, around 10 new lines were constructed within five years, extending the network over 3000 km. In 2020, only 1 out of 41 prefecture-level and above cities in the YRD region did not have HSR connectivity. Such extensive investments made in regional expressway and HSR infrastructure within a relatively short time period provide a useful case to study the impacts of transport improvements with less long-term noise involved.

Recent YRD policies have focused on spatially balanced development within the region. For example, *the Yangtze River Delta Urban Agglomeration Development Plan* (2016) highlights the development of two new city-regions (i.e., Suzhou and Ningbo), in addition to the four traditional economic and political centres in the region (i.e., Shanghai, Nanjing, Hangzhou and Hefei; Fig. 1). Relevant policy initiatives also include *Multi-level Rail Transit Planning in the Yangtze River Delta Region* (2021) and *Higher-quality Integrated Development Plan for Transportation in the Yangtze River Delta Region* (2020). Still, the *Outline of Regional Integration Development Plan in the Yangtze River Delta Region* (2019) emphasises the development of erstwhile lagging-behind areas. Against this backdrop, this study will investigate how improved transport accessibility affects the distribution of growth throughout the region, focusing on the impacts of trunk inland transport networks.

3.2. Spatial equilibrium model

A static SE modelling framework (Jin and Yang, 2022) is extended to examine the varying effects of transport infrastructure changes across the region. This model was first developed by Anas and Liu (2007), and further extended by Jin et al. (2013) for the application to China and the UK (Jin et al., 2019; Jin and Yang, 2022; Yang, 2021). The model employed in this study presents advanced methodological features in two aspects, compared with its earlier version developed by Jin and Yang (2022). First, it explicitly accounts for transport accessibility based on a network representation of HSR and expressways. Second, this model, which is calibrated with historic data for recent years, can produce simulation results taking recent factual market equilibria as baseline conditions for a counterfactual analysis (see Section 3.4; Yang, 2020). The counterfactual analysis is achieved through designing counterfactual model inputs (e.g., zone-to-zone travel time) to compare

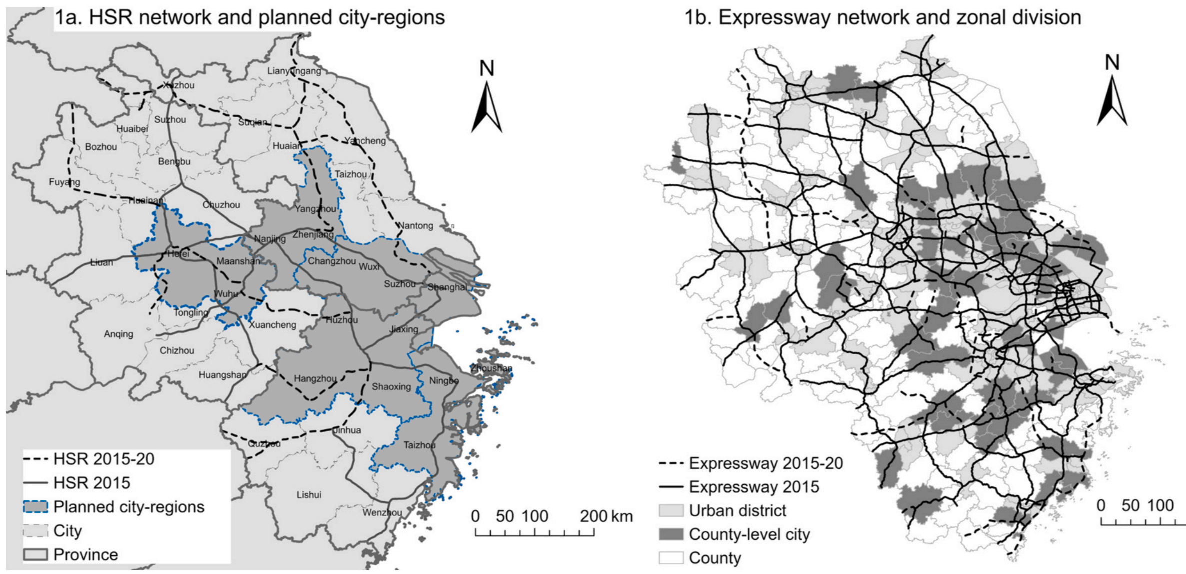

Fig. 1. HSRs, expressways, and model zones in the YRD region.

the difference between new equilibria statuses and a benchmark. While the model has been reported in details elsewhere (Jin and Yang, 2022; Jin et al., 2019), a summary is presented as follows.

The model examines household and firm behaviours within a closed economy, extending conventional neoclassical assumptions (Jin et al., 2019). Producers employ factor inputs (such as business floorspace and labour) to manufacture products at supply prices. These products can either be consumed locally or exported to other areas via transport networks. The prices paid by consumers reflect both production costs and transport margins. Simultaneously, residents determine their residential and work locations, balancing their income against the costs of products and housing. Transport costs play a critical role in these decisions by affecting the desirability of various living and working combinations, primarily due to travel disutility. This, in turn, influences the distribution of where people choose to live relative to their workplaces and the corresponding housing rents. Ultimately, the model allows for the calculation of average utility across different zones by factoring in wage income. Fig. 2 illustrates the primary inputs and outputs of this spatial equilibrium model, along with simulations that provide insights from the consumer's perspective.

To sum up, the impacts in terms of accessibility are simulated by reducing transport costs, represented by travel time. Two primary mechanisms connect alterations in transport costs to model outcomes: (1) Transport costs affect consumption prices, thus influencing the demand for goods and services in distinct areas. (2) Transport costs influence the attractiveness of living-working combinations, leading to a reshuffling of residents and thereby generating new expenditure patterns on housing and products. Model outputs are ultimately evaluated based on changes in the number of employed residents given employment, fluctuations in housing rents (constrained by housing stocks), and consumer surplus (derived from utility, a representation of social welfare; Anas and Rhee, 2006; Jin and Yang, 2022). In addition to transport costs, variables such as employment, housing stock and business floorspace are exogenously established.

This study, centred on counterfactual analysis, selected two specific years for model development based on data availability. The model was calibrated for the year 2015 using observed statistics to ensure the outputs accurately reflect local conditions given the inputs. The travel friction and residential attractiveness were calibrated based on the estimated journey-to-work matrix. Other parameters such as the share of resident' consumption on housing and goods and services were calculated based on local statistics. The calibration was executed with a precision of 10^{-4}. Once calibrated, the SE model is applied to simulating different counterfactual scenarios for year 2020. To evaluate the model's predictive power, changes observed in employment, housing and transportation between 2015 and 2020 were inputted. The simulation results for these variables were then compared with the actual statistics observed in 2020 for a validation purpose. The comparison focused particularly on the data concerning employed residents across various zones. The results showed alignments between the model

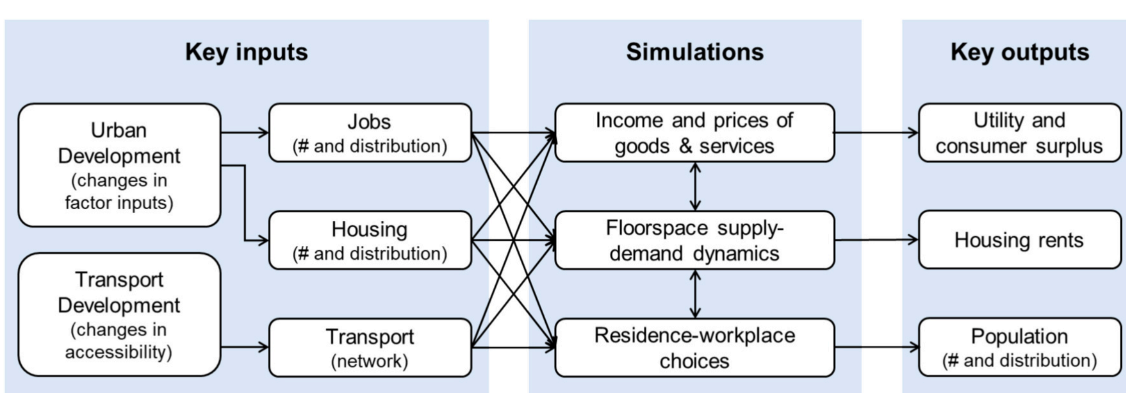

Fig. 2. The key inputs and outputs of the spatial equilibrium model (a consumer perspective).

predictions and observed data for 2020, with an R-squared of 0.9652.

3.3. Zonal division and travel time estimation

The model divides the YRD region into 307 county-level zones, categorised into municipal districts, county-level cities and counties. Considering changes in administrative boundaries and ranks during the study period, socioeconomic variables and statistics are recalibrated according to the 2020 boundaries. Notably, 25 out of the 307 zones underwent this recalibration process.

In accordance with rational travel behaviour, the minimum travel time through the transport network is used to estimate the travel time between the seats of government for individual units. The total travel time between two zones accounts for both intra-zonal and inter-zonal durations, as established by previous studies (Bian and Yeh, 2020; Gutiérrez et al., 2010; Wang, 2018). For intra-zonal travel time calculations (Condeço-Melhorado et al., 2014; Frost and Spence, 1995), an area-based approach with a designated speed of 20 km/h is adopted (Bian and Yeh, 2020; Wang & Duan, 2018).

Inter-zonal travel time is computed from the ArcGIS-based shortest routes between zones and drawing upon speed specifications from earlier studies (Condeço-Melhorado et al., 2014; Wang, 2018): 110, 80, 70, and 40 km/h for controlled-access expressways (*gaosu*), national highways (*guodao*), provincial roads (*shengdao*), and remaining roads, respectively. Actual operating speeds are used for individual HSR lanes, ranging from 200 to 350 km/h. An additional 30 min is included if there is a need to transfer between roads and HSRs. Data on the transport network, including road types, are sourced from OpenStreetMap and Amap.

In instances where a zone contains multiple HSR stations, the algorithm assesses all possible routes and selects the one with the shortest travel time. Thus, while all HSR stations are considered, only the shortest time cost is retained for analysis. The study characterises the impacts of transport accessibility based on the shortest network travel time and does not account for other dimensions of transport services, such as HSR schedules and expressway congestion.

3.4. Socioeconomic data and estimation

The data employed for model development encompass a range of socioeconomic indicators including employment, resident populations, housing stock and business floorspace. These are derived from comprehensive population and economic statistics. Employment figures for individual zones in 2015 and 2020 are interpolated/extrapolated from the National Economic Censuses of 2013 and 2018, utilising the calculated annual growth rates. The resident populations for 2015 and 2020 are sourced from the 1 % National Population Sample Survey conducted in 2015 and the National Population Census of 2020, respectively.

Due to data constraints, housing stock is estimated from the population figures of individual zones and the average household size at the city level. Business floorspace is calculated by considering the employment numbers in each zone alongside the per capita space allocation at the provincial level. These methods for estimating model socioeconomic inputs follow the approach outlined by Jin and Yang (2022). Additional economic indicators, such as wages, are derived from data provided by the statistical bureaux of individual provinces and cities. Table 1 presents the descriptive statistics of key socioeconomic variables for the YRD region.

3.5. Counterfactual scenarios

A set of counterfactual scenarios are developed to examine changes in employed residents, housing rents and consumer surplus under different policy interventions and for the period of 2015–2020 (Yang, 2020). The model, calibrated in 2015, is used to project changes for 2020 with specifically designed inputs detailed below.

Table 1
Statistics of socioeconomic variables in 2015.

Variable	Mean	S.D.	Min	Max
Population: Employed residents (1000 persons)	355.73	256.38	37.44	2622.61
Employment (1000 persons)	387.01	247.23	35.36	2454.37
Business floorspace (1000 units)	7740.18	4944.70	707.21	49,087.41
Housing unit (1000 units)	251.66	182.05	30.68	2214.53
Housing rents (¥1000 per year)	9.13	4.11	2.83	28.62
Wages (¥1000 per year)	38.05	13.41	26.98	73.31

Note: All prices are in the level of 2015.

Counterfactual Scenario 1 (CS1): This scenario explores the impacts of employment growth by incorporating job increments between 2015 and 2020 into the model. Job numbers are updated for 2020, while other factors, such as housing stock and transport network, remain at the 2015 levels.

Counterfactual Scenario 2 (CS2): Building on CS1, this scenario considers the joint effects of changes in employment and housing. Specifically, key model inputs, such as jobs and housing stocks, are updated for 2020. The differences in model outputs between CS2 and CS1 thus reflect the impact of changes in the housing stock.

Counterfactual Scenario 3 (CS3): On top of CS2, travel times in CS3 are updated using the transport network, incorporating expressways constructed during 2015–2020. Therefore, the differences between CS2 and CS3 represent the impacts of these new expressways, everything else being equal.

Counterfactual Scenario 4 (CS4): This scenario further incorporates HSR growth during 2015–2020. Specifically, CS4 updates CS2 with travel time calculations based on transport networks with constructed HSRs. The differences between CS2 and CS4 thus correspond to the impacts of the new HSRs alone.

The 2020 model (for validation purpose) in Section 3.2 is used to represent a "factual scenario" (FS5) and account for observed changes in employment, housing stock and transport improvements, including both expressways and HSRs. Comparing FS5 with CS2 reveals the combined impact of new constructions of both expressway and HSR infrastructure.

The scenarios are designed to facilitate pairwise comparisons and subsequently the differentiation of impacts from urban (i.e., housing stock and jobs) and transport (i.e., expressways and HSRs) development (Jin et al., 2019). To focus on the distribution of growth, the simulation takes the sequence of first employment and housing that influence total growth, followed by transport that reflects distribution effects. The proposed sequence can help isolate the redistributive impacts of transport improvements from the overall growth dynamics (e.g., Rietveld, 1994; Meijers et al., 2012; Jin and Yang, 2022). It thus may provide clearer insights into how accessibility changes may reshape the spatial patterns of economic activities and population (Jin and Yang, 2022).

However, it should be noted that the model assumes exogenous impacts to be independent. For instance, while the model focuses on the direct impacts induced by accessibility improvement, indirect impacts, such as additional employment and housing growth due to transport investments, are not specifically considered in CS3 and CS4. Scenarios also do not account for capacity changes in transport infrastructure. The changes in outputs induced by transport development are solely driven by alterations in zone-to-zone travel time.

4. Results and discussion

4.1. Changes in jobs, housing stocks and transport accessibility

Table 2 provides a detailed breakdown of the changes in model inputs (i.e., employment, housing stocks and transport accessibility) across 307 county-level units between 2015 and 2020. These changes are indicative of broader urban development trends and the impact of

Table 2
Urban and transport developments between 2015 and 2020.

	# Jobs (million)		# Housing units (million)		Average inter-zonal travel time (unweighted, in minutes)			
	2015 (Base year)	2015–20 (%)	2015 (Base year)	2015–20 (%)	2015 (Base year)	2020 (+new expressways)	2020 (+new HSRs)	2020 (+both)
Municipal district	59.55	8.10	40.60	24.42	212	210	186	185
County-level city	26.73	−0.49	16.19	23.53	230	228	199	198
County	32.53	−13.05	20.47	15.86	252	249	218	217
Overall	118.81	0.38	77.26	21.97	228	226	199	198

new transport infrastructures such as expressways and HSRs.

Municipal districts have shown a significant increase in employment over the five-year period, with job numbers growing by 8.1 %, which is considerable given that these areas already accounted for over half the total jobs in 2015. Concurrently, housing units in these districts have surged by 24.4 %. In contrast, county-level units have recorded negative changes in employment; particularly, counties saw a 13.1 % decrease in jobs. However, both county-level cities and counties have experienced substantial growth in housing stocks, with increases of 23.5 % and 15.9 %, respectively. The figures indicate a growing concentration of employment in urban centres, potentially complicating the balanced development goals of the YRD planning.

The study period also saw improvements in inter-zonal travel times, due to transport infrastructure development. Overall, the average travel time across 307 zones or units decreases from 228 to 198 min, a 13.2 % reduction. Nevertheless, the construction of expressways alone contributes to a marginal decrease in mean travel time, accounting for only approximately 2 min out of the 30-min travel time reduction. The majority of time savings can be attributed to investments in HSR networks. Counties are associated with a three-minute decrease in travel time due to expressways and a 34-min reduction due to HSRs. Despite these enhancements, counties still recorded the longest average travel time among the regions studied. Conversely, municipal districts and county-level cities, although also benefiting from reduced travel times, experienced less pronounced improvements.

4.2. Overall impacts of urban and transport development

We first present the effects of urban (i.e., jobs and housing) and transport (i.e., HSRs and expressways) development on the distribution of employed residents, housing rental prices and consumer surplus. As mentioned, transport effects are assessed in comparison to the benchmarking effects of employment and housing. The analysis includes a comparison of relative growth across different types of zones and employs the Gini index to measure the balance in such growth (Cascetta et al., 2020).

Urban and transport development is linked to an overall increase in the number of employed residents (0.38 %), housing rents (7.88 %) and consumer surplus (¥915bn, equivalent to 5.98 % of GDP in 2015) as detailed in Table 3. Municipal districts have witnessed an 8.59 % rise in employed residents during the study period, while county-level cities and counties have experienced a decline by 0.70 % and 12.85 %, respectively. A similar pattern is observed in housing rents, where municipal districts recorded the highest growth of 11.58 %, and county-level cities and counties experienced a minimal increase (0.32 %) and a decrease (−3.59 %), respectively. As for consumer surplus, all regions benefited from the combination of urban and transport development, with the largest changes associated with counties (6.82 % of GDP compared to the regional average at 5.98 %).

The combined effects of urban developments and accessibility improvements have tended to amplify regional disparities, as shown in Table 4. The increasing gap is further evidenced by an increase in the Gini coefficient for the distribution of employed residents (from 0.3294 to 0.3581) and housing rents (from 0.2210 to 0.3007) during 2015–2020. These findings are consistent with prior studies that highlight an uneven distribution of economic activities in the YRD region (Wang et al., 2023; Xu et al., 2021).

Jobs, housing and transport play a distinct role in regional growth and disparities. Changes in employment have the most substantial impact on increasing regional disparities, as measured by Gini coefficients of employed residents and housing rental prices. The effects of housing development may be mixed and moderate, in this case resulting in increased inequality in population distribution but a more equitable housing rent landscape. Improved transport accessibility is linked to decreases in Gini coefficients of employed residents and housing rents and in line with the effects on reducing disparities reported in Liu et al. (2020) and Jiao et al. (2014).[1]

Among the three types of zones, transport development alone leads to increases in employed residents and housing rents in county-level cities and counties, but a decrease in municipal districts. These findings align with Yu et al. (2016, p.225)'s observation that "improvement in the road network (reduction in transport costs) is likely to cause substantial spatial dispersal of economic activity when the transport costs fall below a critical level", as municipal districts in our analysis tend to be more well-endowed with transport infrastructure. Specifically, the YRD region may fall on the right half of the "inverted-U-shaped relationship" between transport and development as suggested in Yu et al. (2016, p.225). Still, expressways and HSRs may have differentiated impacts. For instance, while overall accessibility improvements are associated with increased disparities in consumer surplus, the development of new expressways is associated with a more balanced distribution of consumer surplus across the region (Table 4).[2]

Importantly, it is crucial to underscore that when juxtaposed with other urban development factors such as job creation and housing stocks, the impacts of transport development are rather modest. Judging based on the sheer size of impacts, they may play a supplementary role in shaping the growth and disparities within the YRD region (Meijers et al., 2012; Banister and Berechman, 2001; Bian and Yeh, 2020).

4.3. Impacts at the city-region level

The following analysis narrows its focus to four well-established economic and political centres (i.e., Shanghai, Nanjing, Hangzhou and Hefei) and two emerging city-regions emphasised in recent development plans (i.e., Suzhou and Ningbo), as detailed in Tables 5 and 6. The crux of the analysis is the transport effects within and across these distinct city-regions. The six city-regions are selected based on the *Yangtze River Delta Urban Agglomeration Development Plan* (2016). Areas not included within these six defined city-regions are referred to as non-city-regions. For comparative purposes, city-region-specific findings are also presented.

The contribution to reduced disparities from transport growth is

[1] The results only hold when the transport impacts are examined along with the urban effects.

[2] The condition of this result and accompanying explanations is the same as in footnote #1

Table 3
Impacts of urban and transport development at the regional level.

Items	Zonal category	2015	Changes between 2015 and 2020 (%)						
			Urban development			Transport development			Overall
			Jobs	Housing	Both	Expressway	HSR	Both	
Employed residents (1000 people)	Municipal district	57,948	8.29 %	0.37 %	8.66 %	−0.01 %	−0.05 %	−0.06 %	8.59 %
	County-level city	27,056	−0.45 %	−0.34 %	−0.79 %	0.01 %	0.08 %	0.09 %	−0.70 %
	County	33,808	−12.53 %	−0.36 %	−12.89 %	0.01 %	0.02 %	0.04 %	−12.85 %
	Total	118,812	0.38 %	0.00 %	0.38 %	0.00 %	0.00 %	0.00 %	0.38 %
Housing rents (¥/unit/year)	Municipal district	12,437	39.26 %	−27.62 %	11.64 %	−0.02 %	−0.05 %	−0.06 %	11.58 %
	County-level city	9569	24.31 %	−24.11 %	0.21 %	0.00 %	0.11 %	0.12 %	0.32 %
	County	6092	12.27 %	−15.93 %	−3.67 %	0.03 %	0.04 %	0.08 %	−3.59 %
	Average	10,155	32.02 %	−24.14 %	7.88 %	−0.01 %	0.00 %	0.00 %	7.88 %
Consumer surplus (%GDP)	Municipal district	–	3.96 %	1.45 %	5.42 %	0.02 %	0.27 %	0.29 %	5.71 %
	County-level city	–	4.80 %	1.04 %	5.83 %	0.02 %	0.28 %	0.29 %	6.13 %
	County	–	5.71 %	0.86 %	6.57 %	0.03 %	0.22 %	0.24 %	6.82 %
	Total	–	4.44 %	1.26 %	5.70 %	0.02 %	0.27 %	0.28 %	5.98 %

Note: Consumer surplus (in monetary term) between 2015 and 2020 is analysed using the local GDP in 2015 as a reference point for comparison.

Table 4
Effects of urban and transport development at the regional level (measured by Gini index).

Items	2015	Changes between 2015 and 2020						
		Urban development			Transport development			Overall
		Jobs	Housing	Both	Expressway	HSR	Both	
Employed residents	0.3294	0.0243	0.0044	0.0288	−0.0000	−0.0001	−0.0001	0.0287
Housing rents	0.2210	0.0804	−0.0005	0.0799	−0.0001	−0.0002	−0.0002	0.0797
Consumer surplus	–	0.4074	0.0170	0.4244	−0.0005	0.0012	0.0009	0.4253

Notes: The concept of consumer surplus is based on the differences in utility between 2015 and 2020. Therefore, there is no corresponding Gini value for consumer surplus in 2015, as this measure is derived solely from the changes in utility.

Table 5
Impacts of urban and transport developments at the city-region level.

Items	Zonal category	2015	Changes between 2015 and 2020 (%)						
			Urban development			Transport development			Overall
			Jobs	Housing	Both	Expressway	HSR	Both	
# Employed residents (1000 people)	Shanghai	11,059	15.31 %	−0.10 %	15.20 %	0.00 %	0.00 %	0.00 %	15.20 %
	Nanjing	8146	0.28 %	0.11 %	0.39 %	−0.01 %	−0.01 %	−0.02 %	0.38 %
	Hangzhou	12,230	22.64 %	0.01 %	22.65 %	0.00 %	−0.20 %	−0.19 %	22.46 %
	Hefei	6948	3.24 %	0.12 %	3.36 %	0.00 %	−0.08 %	−0.08 %	3.29 %
	Suzhou	13,363	4.78 %	0.09 %	4.87 %	0.00 %	0.00 %	0.00 %	4.87 %
	Ningbo	8735	13.05 %	0.01 %	13.06 %	0.00 %	0.00 %	0.00 %	13.06 %
	City-regions	60.482	10.73 %	0.03 %	10.76 %	0.00 %	−0.05 %	−0.05 %	10.71 %
	Non-city-regions	58,330	−10.36 %	−0.03 %	−10.39 %	0.00 %	0.05 %	0.05 %	−10.34 %
Housing rents (¥/unit/year)	Shanghai	18,503	42.14 %	−10.13 %	32.01 %	−0.02 %	0.00 %	−0.01 %	32.00 %
	Nanjing	11,149	26.33 %	−27.31 %	−0.99 %	−0.01 %	−0.01 %	0.00 %	−0.99 %
	Hangzhou	12,314	58.03 %	−48.71 %	9.32 %	0.01 %	−0.22 %	−0.20 %	9.11 %
	Hefei	8033	18.64 %	−13.17 %	5.46 %	0.00 %	−0.11 %	−0.10 %	5.37 %
	Suzhou	11,857	27.53 %	−27.75 %	−0.21 %	0.00 %	0.00 %	0.01 %	−0.20 %
	Ningbo	12,371	36.61 %	−28.25 %	8.36 %	0.00 %	0.00 %	0.01 %	8.37 %
	City-regions	13.063	38.32 %	−27.20 %	11.12 %	−0.01 %	−0.05 %	−0.05 %	11.07 %
	Non-city-regions	6835	13.99 %	−16.99 %	−3.01 %	0.00 %	0.10 %	0.10 %	−2.90 %
Consumer surplus (%GDP)	Shanghai	–	1.98 %	0.81 %	2.79 %	0.01 %	0.22 %	0.23 %	3.02 %
	Nanjing	–	4.02 %	1.15 %	5.14 %	0.02 %	0.22 %	0.23 %	5.38 %
	Hangzhou	–	4.56 %	2.38 %	6.91 %	0.03 %	0.29 %	0.31 %	7.22 %
	Hefei	–	5.17 %	1.61 %	6.76 %	0.01 %	0.25 %	0.26 %	7.02 %
	Suzhou	–	4.04 %	0.95 %	4.97 %	0.02 %	0.24 %	0.26 %	5.23 %
	Ningbo	–	5.68 %	1.97 %	7.63 %	0.02 %	0.40 %	0.42 %	8.05 %
	City-regions	–	3.90 %	1.36 %	5.24 %	0.02 %	0.26 %	0.27 %	5.52 %
	Non-city-regions	–	5.71 %	1.09 %	6.77 %	0.03 %	0.28 %	0.30 %	7.07 %

Note: Consumer surplus (in monetary term) between 2015 and 2020 is analysed using the local GDP in 2015 as a reference point for comparison.

confined to city-regions (Liu et al., 2020; Yu et al., 2016). Specifically, improved transport accessibility is associated with decreases in Gini coefficients of employed residents, housing rents and consumer surplus within city-regions alone. For areas outside these city-regions, changes in Gini coefficients associated with transport development are positive.

The variegated landscape can be linked to differing existing levels of accessibility and distinct relative changes. As city-regions generally have more developed transport infrastructure, planned improvements may mainly bridge connectivity gaps in the network. In contrast, non-city-regions may be undergoing development of backbone infrastructure that first connects key settlements, potentially increasing spatial disparities. This contrast between city-regions and non-city-regions may be

Table 6
Effects of urban and transport developments at the metropolitan level (measured by Gini index).

Items	Zonal category	2015	Changes between 2015 and 2020						
			Urban development			Transport development			Overall
			Jobs	Housing	Both	Expressway	HSR	Both	
# Employed residents	Shanghai	0.3683	0.0094	0.0069	0.0164	0.0002	−0.0001	0.0001	0.0165
	Nanjing	0.2283	0.0054	−0.0039	0.0015	0.0001	0.0000	0.0001	0.0016
	Hangzhou	0.2437	0.0110	0.0262	0.0372	−0.0005	−0.0008	−0.0013	0.0359
	Hefei	0.2842	0.0701	0.0073	0.0774	−0.0000	−0.0004	−0.0004	0.0770
	Suzhou	0.2469	−0.0169	0.0035	−0.0135	0.0000	−0.0001	−0.0001	−0.0135
	Ningbo	0.3180	0.0207	0.0025	0.0232	0.0000	−0.0000	−0.0000	0.0232
	City-regions	0.3141	0.0139	0.0079	0.0219	−0.0001	−0.0002	−0.0002	0.0216
	Non-city-regions	0.3374	0.0105	0.0005	0.0110	0.0001	0.0003	0.0003	0.0113
Housing rents	Shanghai	0.1405	0.0630	0.0095	0.0725	−0.0004	0.0001	−0.0004	0.0721
	Nanjing	0.1200	0.0791	0.0114	0.0905	0.0001	−0.0000	0.0000	0.0905
	Hangzhou	0.0833	0.0829	−0.0201	0.0628	−0.0004	−0.0005	−0.0009	0.0619
	Hefei	0.1650	0.0671	−0.0124	0.0547	−0.0000	−0.0002	−0.0002	0.0545
	Suzhou	0.0593	0.0424	−0.0018	0.0406	0.0000	0.0000	0.0001	0.0407
	Ningbo	0.0822	0.0615	−0.0216	0.0399	0.0001	0.0000	0.0001	0.0400
	City-regions	0.1646	0.0704	0.0186	0.0890	−0.0002	0.0000	−0.0002	0.0888
	Non-city-regions	0.1799	0.0739	−0.0333	0.0407	−0.0001	0.0001	0.0001	0.0407
Consumer surplus	Shanghai	–	0.4535	0.0287	0.4822	−0.0023	−0.0111	−0.0131	0.4691
	Nanjing	–	0.2644	−0.0010	0.2634	0.0002	0.0007	0.0008	0.2642
	Hangzhou	–	0.3268	0.0195	0.3463	−0.0011	−0.0032	−0.0038	0.3425
	Hefei	–	0.2743	0.0780	0.3523	0.0000	0.0050	0.0049	0.3572
	Suzhou	–	0.2501	−0.0088	0.2413	−0.0004	−0.0003	−0.0005	0.2408
	Ningbo	–	0.3343	0.0096	0.3439	−0.0001	0.0001	0.0000	0.3439
	City-regions	–	0.3654	0.0059	0.3712	−0.0005	−0.0011	−0.0015	0.3698
	Non-city-regions	–	0.3844	0.0164	0.4008	−0.0004	0.0064	0.0061	0.4069

Notes: As above, the Gini index of consumer surplus is the value in 2020 in the jobs and both of urban developments and overall column.

associated with the different impacts of expressway and HSR development under different economic contexts (Baum-Snow et al., 2017; Jiao et al., 2020; see also, Jedwab and Moradi, 2016).

Moreover, the impacts of transport development on employment residents and housing rents vary within each individual city-region. The transport effects show even wider diversity in terms of consumer surplus, with Hangzhou (−0.0038), Shanghai (−0.0131), and Suzhou (−0.0005) witnessing a decline in the Gini coefficient, while Hefei (0.0049) and Nanjing (0.0008) experience an increase. These results underscore the need for more localised policy-making, in line with the recommendations of Garin (2019), Geng et al. (2015) and Mohammad et al. (2013).

5. Conclusions

This study applies a static spatial equilibrium model to assess the impacts of newly constructed expressways and high-speed railways. By examining the interplay between supply-demand dynamics and production-consumption behaviours, enhancements in accessibility only induce modest impacts on employed residents, housing rents and consumer surplus, compared with urban developments in this model (i.e., jobs and housings). This finding is consistent with studies that identify transport infrastructure as having a "supporting," rather than dominant, role (Meijers et al., 2012, p.189; Banister and Berechman, 2001; Spiekermann and Wegener, 2006; Bian and Yeh, 2020).

Given the limited effects of transport infrastructure on reducing regional disparities, the sheer size of impacts from job and housing changes, as well as potentially contrasting impacts from urban and transport development, future policies targeting geographically even development may require a careful consideration of the synergies between urban and transport policies. For example, for areas lacking robust transport networks, despite the immediate social and economic benefits that improved transport accessibility might bring, local authorities may need to take into consideration the potential risk of increased disparities (Wang, 2018; Allen and Arkolakis, 2022). Regional and local development plans should be strategically coordinated to optimise the effects of transport infrastructure development, ensuring that the benefits are widespread and contribute to reducing disparities (Hiramatsu, 2018).

The SE analysis presented in this study can be improved in several key aspects. First, the sequence of incorporating urban and transport changes may matter, considering the interactions between urban and transport changes in the model (Fig. 2) as well as the non-linear relationship between urban and transport development (Yang et al., 2019). The effects of transport development reported in this study (e.g., CS3 and CS4) are conditional on urban development (e.g., CS1 and CS2). As a robustness check, the effects of transport development are simulated without inducing new employment and housing (CS6). Specifically, "the effects of transport development" on employed residents in county-level cities are currently measured as the difference between FS5 and CS2 and reported as 0.09 %. By contrast, if we measure "the effects of transport development" by the differences between employed residents reported in CS6 and those observed in 2015, the estimated effects would become 0.07 %. In this case, the direction of the effects remains while the magnitude of the effects changes.[3] As noted above, some of the conclusions reported in this study only hold when transport effects are simulated on top of urban effects. For future practice, it may be desirable to gauge the '"average'" effects of transport development given different levels of changes in the urban sector.

Second, the model largely aggregates industrial sectors, although transport impacts may vary across sectors (Meijers et al., 2012; Vickerman et al., 1999). Third, travel costs, currently measured by travel time, may overlook other influential factors such as tolls or congestion. Including these service-related considerations, such as time schedules, can lead to a more precise evaluation of transport impacts (Anas and Rhee, 2006). Lastly, the effects of intra-regional transport improvements on the rest of the country are not addressed; imports and exports across

[3] Note that deviations in both the direction and size of effects by transport development may take place. Exceptions in terms of transport effects are on disparities in employed residents and consumer surplus. For example, when comparing CS6 and FS5 under the assumptions of no urban developments but transport improvements alone, the change in Gini index shifts to 0.00001, as opposed to −0.0001 (reported in Table 4).

the regions in different counterfactual scenarios are assumed to be the same as in the factual scenario. Despite these strong assumptions, their impact on the core conclusions of this study is likely limited (e.g., Dong et al., 2022; Xu et al., 2020), given the relatively short research period of five years and the substantial size of the YRD region, which exceeds that of the United Kingdom. The analytical framework developed here is suited for future application in both national and international contexts, which could provide deeper insights into the trade-offs associated with transport infrastructure developments across regions and nations.

CRediT authorship contribution statement

Junxi Qu: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Tianren Yang:** Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Kyung-Min Nam:** Writing – review & editing, Conceptualization. **Euijune Kim:** Writing – review & editing, Conceptualization. **Yimin Chen:** Writing – review & editing, Conceptualization. **Xingjian Liu:** Writing – review & editing, Writing – original draft, Funding acquisition, Formal analysis, Conceptualization.

Data availability

Data will be made available on request.

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