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UNRAVELING THE IMPACT OF DIGITAL HIGHWAY PROJECTS ON ECONOMIC GROWTH: REGIONAL COMPETITIVENESS PERSPECTIVE

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Abstract. Highway projects that harness digital technologies during operation (known as digital highway projects; DHPs) can stimulate economic growth, but limited efforts have been made to fully unravel this mechanism. To address this void, this study examined the impact of DHPs on the economic growth. Specifically, under the auspices of the regional competitiveness theory, the development level of DHPs, transportation demand, new factor endowments, and related and supporting industries were identified and measured first, and their impact on economic growth was then unearthed using data from 11 operational DHPs and a partial least squares structural equation modeling (PLS-SEM) framework. It was observed, from the perspective of stakeholders of our DHPs, that DHPs increase transportation demand, which in turn has a positive effect on a new factor endowment (i.e., data flow) and the development of related and supporting industries, with the former (β = 0.859, p < 0.001) being impacted more than the latter (β = 0.363, p < 0.001). In addition, new factor endowment has a statistically significant impact (β = 0.666, p < 0.001) on the economy, while the development of related and supporting industries is insignificant (β = 0.095, p > 0.05). Finally, although DHPs promote economic growth, this path can be mediated by increased transportation demand and subsequently by the new factor endowment including data flow. As such, this study further develops the regional competitiveness theory in the context of DHPs and provides new empirical evidence on the 'transportation induced demand' effect and the growth theory. Practically, this study arms policymakers with a better understanding of how DHPs influence the regional economy, and offers effective and targeted recommendations for managing these projects.

Keywords: digital highway projects, economic growth, PLS-SEM, regional competitiveness theory.

JEL Classification: C83, H54, O22, R11, L91.

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1. Introduction

Traditionally, highway projects impact the economy by directly improving the efficiency and productivity of movements, and by indirectly influencing such factors as trade, labor force, and urbanization (Beyzatlar et al., 2014). For instance, the Chengdu–Chongqing road in China and the Bamenda–Mamfe highway in Cameroon have significantly prompted the growth of cities along their routes (Tende et al., 2024; Wan et al., 2024). In the digital era, due to the unprecedented convergence between digital technologies (e.g., 5G, edge computing, and Internet of Things) and highways, their capabilities in linking different cities, reducing transportation costs and improving cross-regional accessibility have been further enhanced (Mattsson & Jenelius, 2015). Notably, these Digital Highway Projects (DHPs) have built "data channels" using digital technologies to ensure safe, efficient, and high-quality transportation through the transmission and analysis of traffic data (Lee & Yoon, 2021; J. Wang et al., 2022). Therefore, this presents opportunities to explore how the emerging DHPs impact economic growth differently to ensure a sustainable development of future DHPs.

In contrast to traditional highways, DHPs primarily embody two types of digital scenarios: digital service ecosystems and digital travel solutions (Mattsson & Jenelius, 2015). Digital service ecosystems (e.g., smart parking and road information announcements) improve travel experience for drivers and passengers (C. Li et al., 2023). Digital travel solutions, including autonomous driving, all-weather travel, and intelligent emergency management platforms, provide optimized driving routes and traffic signals using transport data to meet increasing transportation demand and accelerate the diffusion of the labor force and digital technologies (Mahmood et al., 2022). In New York, for example, using bus telematics of intelligent traffic systems has resulted in a 5–14% increase in bus speeds (Intelligent Transportation Society of America [ITS America], n.d.). As such, these digital travel solutions have enhanced the flow efficiency of urban population and capital investment. Furthermore, developing DHPs is closely related to advanced sensor technologies (e.g., light detection and ranging, radar, camera) and networking and communication technologies, contributing to the digital upgrading of the industrial structure (Nham et al., 2023). Such digital characteristics of DHPs can foster new competitive advantages of cities along the route by not only increasing transportation demand (Dabiri & Heaslip, 2018), but also by accelerating the cross-regional flow of factor endowments (e.g., labor force, digital technologies, and capital investment) (Mahmood et al., 2022) and developing the digital industry (Nham et al., 2023).

Existing literature has explored the influence mechanism between transportation projects and growth, including cooperation between cross-regional enterprises productivity (X. Yang et al., 2019), market access (Herzog, 2021), industry aggregation (J. Wang et al., 2022), urbanization (Chanieabate et al., 2023), capital utilization efficiency (J. Zhang et al., 2021), and competitiveness (Niu et al., 2020; Zheng et al., 2011). For instance, Herzog (2021) calibrated a general equilibrium trade model to suggest that unplanned highways can cause differences in market access, and thus led to adverse economic conditions. Chanieabate et al. (2023) used mediating effect model to highlight the role of transportation infrastructure in improving urbanization, which contribute to narrow income disparities and promote regional economic balance. However, there are problems with prior studies. First, existing studies have explored the impact of traditional highways on regional economy, but the digital features of DHPs (e.g., the application of digital technology, the analysis of data flow, and digital industrial innovative) and the new competitive advantages are at their infancy. Second, existing studies focused on a single factor affecting growth by utilizing based-objective-data linear regression model (Chanieabate et al., 2023; J. Zhang et al., 2021) rather than systematically identifying various influence factors that affect growth in a complex and interactive manner. Third, as DHP is an emerging industry developed in recent years, there is limited macro data about DHPs and the regional development (e.g., economy, population, technology, and capital) affected by DHPs. It is difficult to collect enough actual data to reveal the relationships between DHPs and economic growth. However, as a common method of collecting individual data, using stakeholders' perspective to understand this relationship has been neglected in the existing research.

Motivated by these gaps, this study aims to explore the influence mechanism between DHPs and economic growth from a regional competitiveness perspective by addressing the following research questions: (1) *How do influence factors specific to DHPs individually and collectively affect economic growth? and* (*2*) *How can policymakers develop DHPs to maximize regional growth?* To do so, we identify the influence factors of economic growth from the perspective of regional competitiveness and proposed six hypotheses to illustrate their relationships (Section 2). Specifically, we hypothesize that the development of DHPs can stimulate transportation demand, which in turn drives the growth of new factor endowments and related industries, ultimately fostering economic development. Additionally, the expansion of new factor endowments further benefits related and supporting industries. Then, these hypotheses are examined by surveying stakeholders from 11 operational DHPs and implementing a Partial Least Squares Structural Equation Modeling (PLS-SEM) framework (Section 3). The results are subsequently presented and discussed in Sections 4 and 5, respectively before we draw conclusions in Section 6. As a result, contributions of this study are fourfold. First, this study adds digital advantages into the regional competitiveness theory to reflect new characteristics of DHPs that are different from traditional highways. Second, it injects evidence to the "transportation induced demand" effect by attributing demand increase to increased road capacity, improved traffic safety, and enhanced traffic information transmission. Third, this study contributes to the development of the growth theory as it identifies that data flow, as a new factor endowment in addition to technological change, labor and capital inputs, is essential for economic growth. Finally, practically, it offers insights for policymakers on how to effectively grow regional economy via DHPs by unravelling their impact mechanisms from the perspectives of stakeholders and the regional competitiveness theory.

2. Theoretical background and hypotheses

2.1. Regional competitiveness theory in DHP and economic growth

Competitiveness occurs when a region develops an attribute or a combination of attributes that allows it to outperform its competitors, manifesting in the competitiveness of companies, industries, and/ or national economies (Drescher & Maurer, 1999). Accordingly, the regional competitiveness theory has been extensively applied to study this economic performance of regions by analyzing factors like innovation, infrastructure, and human capital that drive economic growth. Competitiveness can directly determine growth rate and productivity (Breton, 1998). For instance, Organization for Economic Cooperation and Development [OECD] (1992) shares the view that competitiveness, under favorable market conditions, can capacitate the growth of real domestic income. Bris (2014) argues that competitiveness effectively improves living standards and enhances social welfare. In comparison, this theory can be less applicable to such fields as non-competitive economic sectors and purely theoretical economics. For instance, social infrastructure – such as schools, hospitals, and public utilities – focuses on social welfare, which may not align well with a competitiveness framework, as their success is not measured by market competition (Latham & Layton, 2019). With the growth of the economy, many regions are implementing or planning to launch transport infrastructure projects (Niu et al., 2020). The significant domestic demand has sparked intense competition within the DHP industry. As such, regional competitiveness is an effective perspective for studying economic development in the emerging DHP market.

To measure this competitiveness, the "diamond model" was proposed by Porter (1990), including domestic demand conditions, related and supporting industries, factor endowments, and corporate strategies. Following Porter, many studies have adapted the classical model by adding new contributing factors or adjusting parameters (Fang et al., 2018). For example, applying Porter's model to the textile industry, labor force availability, average labor costs, raw materials, geographical location, and research and innovation were found to impede regional productivity. Cho (1994), taking Korea as an example, developed three categories of competitiveness, namely, physical, human, and governmental. A key element, knowledge absorption and innovative ability, was added to the "diamond model" for developing sustainable competitiveness. In the transportation sector, Zheng et al. (2011) added bottlenecks to the diamond model to analyze the regional competitiveness stemming from combined river-sea transport. More recently, technology conditions and international reputation were added to the diamond model by Niu et al. (2020), to explain the determinants of international competitiveness in the high-speed railway industry. However, they lack consideration into the digital features of DHPs.

Although both traditional highways and DHPs can shorten geographical distances and reduce transportation costs, DHPs emphasize the use of digital technologies and the connection of cross-regional traffic data to develop new operational models. Specifically, rapid responses to traffic control, especially in the management of accidents and backups, have been enabled by harnessing traffic "big data", thereby improving traffic efficiency and transportation demand. Real-time data on speed, traffic congestion, directions and the locations of speed checks navigate travelers to make informed decisions for better and more efficient planning of their routes, which contribute to labor flow and technology diffusion to a greater extent (Tseng et al., 2018). In the case of advanced machine learning algorithms, in-vehicle computing platform and vehicle-to-everything technology are beneficial for industry digital upgrading and digital industry development. Together, according to Kušić et al. (2023), they generate new competitive advantages in increased transportation demand, distribution of new factor endowments, and digital industrial innovative, thereby increasing economic level on a sustainable basis. Therefore, Porter's regional competitiveness theory remains relevant for investigating the mechanism of DHPs and economic growth, but new contextual factors need to be considered.

First, according to Deng et al. (2013), the transport infrastructure stock is an important determinant of regional competitiveness. In addition to prompting the stock of transportation infrastructures, the development of DHPs improves information transmission and software technologies, and science research and technology services, which may further trigger economic competition across regions. Second, Porter (1990) pointed that demand conditions refer to the size and nature of the customer base for products. Different from traditional highways, with the support of digital infrastructure (e.g., 5G, data Centers, computing power, and base station), transportation demand for DHPs should be extended from freight/passenger carrying capacity to the safety level and traffic data transmission (Kušić et al., 2023). Third, DHPs' data resource should be added to Porter's (1990) original factor endowments (skilled labor, technological innovation, and capital). This is because exchanging and sharing data across departments, industries, and regions can facilitate the flow of labors, logistics, vehicles and capitals (R. Liu et al., 2025). Importantly, the "digital economy," in which data resources are used as a key production factor to improve and optimize economic structure, has become a new avenue for growth (H. X. Wu & Yu, 2022). Fourth, DHPs not only can enable upstream and downstream industries to agglomerate due to the reducing traffic costs and time (Chatman & Noland, 2011), but also have the potential to upgrade industries for digitalization with the development of digital infrastructure. Therefore, our study proposes that DHPs can prompt economic growth by developing specific competitiveness.

2.2. Research hypotheses

According to the induced demand theory (Hymel, 2019), reduced travel time and commuting costs often result in an increase in modern travel demand (Hymel, 2019). This positive effect on transportation demand also applies to DHPs (Cervero, 2003; Hymel, 2019). Unlike traditional highways, DHPs enhance the applications of digital technologies (e.g., vehicle path guidance platforms and emergency accident warning systems), reduce travel time and cost, expand transportation modes, increase passengers' confidence in travel, and enhance travel flexibility, and thus public demand for modern transportation infrastructure is expected to grow (Andersson et al., 1990). Notably, this demand is not only about the road traffic volume but also about the transportation service quality (including transportation information transmission and traffic safety) (Chabot et al., 2018). Accordingly, we hypothesize:

H1: *Developing DHPs is positively associated with increased transportation demand.*

The new economic geography considers transportation distance and logistics costs as the most important factors influencing the flow of factor endowments (Krugman, 1991). The expansion of transportation capacity can expand the scope and frequency of intercity connections and reduce transportation costs (Lin et al., 2019), which enhances the flow efficiency of labor and technology (Lakshmanan, 2011; J. Sun et al., 2022). In addition, increased transportation demand for DHPs enhances the cross-regional collection, transmission, and analysis of transportation data brought by the developed digital technologies (e.g., sensors, computing power, and artificial intelligence) (Hilbert, 2015; Myovella et al., 2020). In today's hyperconnected information world, multisource and real-time perception facilities are installed alongside roads and linked to traffic management websites to collect and disseminate more data on travel and road conditions. Subsequently, the application of transport data can improve the efficiency and safety, further facilitating the movement of labor and technology across knowledge- and labor-intensive regions (Lakshmanan, 2011; J. Sun et al., 2022). Furthermore, the increased digital transportation capacity can guide the flow and training of scientific and technological talents, thereby increasing employment opportunities in related fields, such as transportation engineering, data science, and artificial intelligence. This is evidenced in the existing studies that have examined the impacts of increased transportation demand on new factor endowments (Makhlouf & Helali, 2024; Paaswell, 2010; Y. Yang et al., 2022). Therefore, we derive the following hypothesis:

H2: *Increased transportation demand is positively associated with new factor endowment.*

Based on increased transportation capacity, inter-regional trade, labor and capital flow can be accelerated by reducing transport costs and commute time (Lin et al., 2019; Melo et al., 2016), thereby strengthening technology-intensive industrial agglomeration benefits (B. Wu & Yang, 2022). Meanwhile, increased transportation demand can accelerate the development of DHPs, thereby improving the related industrial upgrade to digitalization. Specifically, various related-DHPs digital industries (e.g., 5G, distributed data centers, autonomous driving platform, semiconductors, software development, and smart hardware), can be developed quickly. DHPs also provide a development platform for green and intelligent transportation technologies such as autonomous driving and electric vehicles, thereby improving the application of the new energy vehicle industry. Empirical studies have shown that improving transportation capacity can enhance the related and supporting industries (Chang et al., 2021; B. Sun et al., 2017), and thus we hypothesize:

H3: *Increased transportation demand is positively associated with the development of related and supporting industries.*

Industrial development (e.g., industrial-scale expansion, clustering, and structure upgrading) is mainly caused by the mobility and agglomeration of factor endowments between regions (Fujita & Thisse, 2003). Specifically, as DHPs reduce cross-regional commuting time, labor is more likely to flow to areas with higher marginal returns, which is beneficial at the industrial scale (Bloom & Freeman, 1986). The "profit-seeking nature" of capital means that capital will flow to regions with complete industrial ecology conditions to obtain higher returns, promoting industrial clustering (Hawtrey, 1951). Once industrial agglomeration occurs, areas with a high degree of agglomeration attract more factor endowments based on their agglomeration advantages (C. Peng et al., 2022). In contrast to traditional highway projects, DHPs are closely related to the application of digital technologies. Improving accessibility breaks down technological barriers in different regions, thereby stimulating industrial structure upgrades. We, therefore hypothesize that:

H4: *New factor endowment is positively associated with the development of related and supporting industries.*

Theoretical frameworks for economic growth include exogenous and endogenous theories (Lucas, 1988). According to the exogenous theory (Solow, 1956), technological change is not explicitly incorporated into the growth model, leading to what is termed the "Solow residual" (Kenis & Provan, 2009). Any observed growth beyond what can be attributed to labor and capital inputs is attributed to the "Solow residual", indicating the positive impact of technological progress on economic growth. In the following, the endogenous theory incorporates technological change as an endogenous variable of growth (Pack, 1994). As a result, labor, capital, and technology are factors in a growing economy. Notably, data resources represent a significant asset in a data-driven economy, which is considered a new factor endowment worldwide. Mueller and Grindal (2019) suggest that all trade and market development require data flow exchanges to promote economic growth. Considering this perspective, DHPs provide channels for data interaction and information sharing for governments and enterprises through intelligent transportation systems and data exchange platforms. These traffic data contribute to accelerate the transmission and feedback of information, enable enterprises to adjust production plans in real time, provide users with scientific and efficient services, optimize resource allocation, and reduce production costs (Marotta et al., 2018). Furthermore, growth accounting and econometrics have been used to verify the positive effects of capital accumulation, population growth, technological progress (Jorgenson & Vu, 2016; Lucas, 1988; Solow, 1956; Venturini, 2015), and data flow (Cai et al., 2022; Ciampi et al., 2021; H. X. Wu & Yu, 2022). Hence, we derive one more hypothesis:

H5: *New factor endowment is positively associated with economic growth.*

The regional economic growth self-strengthening model indicates that economic growth is influenced by the complex interactive relationships between various industries (Hoover, 1936). The positive externality brought about by upstream and downstream industries can strengthen the agglomerated economy (Hoover, 1936). For instance, industry clustering along the DHPs would prompt the sharing of innovative knowledge and technology, thereby reducing technological costs and promoting economic efficiency (Ren et al., 2021). Meanwhile, the agglomeration and scale effects incurred by industrial development increase the returns to scale, thus prompting economic growth. Importantly, the development of DHPs related digital technologies contributes to the rise of emerging industries, such as e-commerce, sharing economy, smart cities, and digital entertainment. The rapid development of these industries has promoted economic growth. With the help of these digital infrastructures, traditional industries also can achieve digital transformation, which utilize technologies such as cloud computing, big data, artificial intelligence and blockchain to improve operational efficiency and innovate business models. D. Peng et al. (2022), Widodo et al. (2014), Nurlestari and Oktavilia (2023) have empirically verified the close relationship between the development of related and supporting industries and economic growth. Therefore, we hypothesize:

H6: *The development of related and supporting industries is positively associated with economic growth.*

To recap, following the regional competitiveness theory, DHP development level (DHP), Increased Transportation Demand (ITD), new factor endowments (RPF), and the development of related and supporting industries (DI) are posited as determinants of new competitive advantages. According to the above hypothetical paths of H1–H6, the theoretical model for exploring the impact of DHP on Economic Growth (EC) is illustrated in Figure 1.

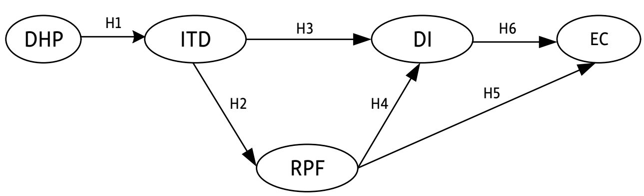


Figure 1. The theoretical model for exploring the impact of DHP on EC

3. Research method

Figure 2 illustrates the research framework of this study. Based on the theoretical background and the six research hypotheses, this study firstly developed the measurement model (Table 1) for the five constructs of the theoretical model (Figure 1). Secondly, empirical data were collected from 11 DHPs case using a questionnaire survey. Finally, Partial Least Squares Structural Equation Modeling (PLS-SEM) was implemented to verify (i.e., hypotheses testing) the influence mechanism between DHPs and economic growth followed by discussion and implications.

3.1. The measurement model

To test the hypotheses outlined above, measurement models of the five constructs are developed as Table 1 based on previous research. First, DHP, which combines the characteristics of transportation infrastructure and information technologies, has the potential to move people and goods more efficiently, safely, and at a lower cost. The development of DHP is the result of interactions between digital industries (e.g., information transmission and software industry), transportation industries, and scientific research and technology service industries (Eicher & Strobel, 2008; Lin, 2019; Qu & Pinsonneault, 2022; S. Yang et al., 2020). It comprises three measurement items: information transmission and software industry level, transportation industry level, and scientific research and technology service industry level.

Second, DHP further increases ITD. Specifically, DHP can increase the passenger and freight capacity demands to a great extent through the use of smart traffic lights and route planning systems (P. Wang et al., 2018). It has also developed many proactive solutions, such as roadway safety monitoring programs, to improve traffic safety levels (L. Wu et al., 2015). In contrast to traditional highway projects, real-time data analysis and transmission functions supported by sensors and data centers are the basis for digital scene applications in DHP; thus, they can be regarded as a new transportation demand (Y. Peng et al., 2019). The ITD was assessed using

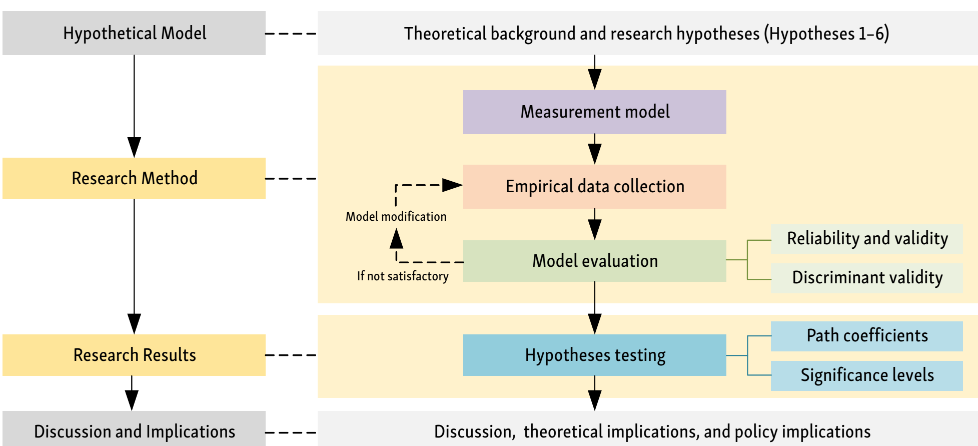


Figure 2. The research framework

a 3-item scale based on P. Wang et al. (2018), L. Wu et al. (2015), Yang et al. (2018), Peng et al. (2019) and J. Wang et al. (2018), to capture the characteristics of freight/passenger carrying capacity, traffic safety, and transportation information transmission.

New RPFs (e.g., labor, technology, capital, and data flow) are more important in improving regional competitiveness than natural factors (e.g., land and natural resources) (Porter, 1990). Specifically, DHP is likely to encourage cross-regional labor transfer owing to low transport costs, less commute time, and high-quality travel experiences. DHP encourages emerging technologies, such as cloud computing and the Internet of Things (Appiah-Otoo & Song, 2021), thus enhancing advanced digital technology applications and diffusion (Pan et al., 2022). Additionally, various DHP-related digital industries can be extended, which benefits capital mobility between industries (from traditional to information industries). Notably, DHP can further transfer and analyze massive amounts of transport data through multi-source and real-time perception facilities, which differ from traditional highways (Barba-Sánchez et al., 2018; Giudici & Pérez-Fortes, 2022). Therefore, RPF was assessed using a 4-item, including human resources transfer level, advanced digital technology level, capital mobility level, and data collection, transmission, and analysis capabilities level (J. Chen & Mei, 2018; Ciampi et al., 2021; Myovella et al., 2020; Vu, 2011; Vu et al., 2020; Ye et al., 2024; Zeng, 2015).

DI can prompt industrial clustering, upgrade industrial structure, and expand industrial scale. Specifically, as DHP improves inter-regional connectivity and reduces transportation costs, industries are more likely to gather along these road projects (Z. Liu et al., 2022). Owing to the use of 5G, the Internet of Things, cloud computing, and artificial intelligence, the development of DHP can stimulate industrial digitization and industrial structure upgrades (T. Wu & Shao, 2022). As the development of DHP involves information and transportation industries, developing DHP can simultaneously expand the scale of these two industries. Overall, DI was measured using three items: the improvement level of industrial clustering, the improvement level of upgrading industrial structure, and the improvement level of industrial scale (Deng et al., 2013).

Finally, EC is closely related to the industrialization level, urbanization level, balanced economic development of urban-rural areas, and the share of employment. Industrialization is the process of transforming or adding value, leading to the creation of semi-finished and finished products (Yuni et al., 2023). These products generate revenue through local and international sales, which is an important aspect of economic growth (Brahmasrene & Lee, 2016). Urbanization contributes to population agglomeration, technological spillover, and service diversification (Z. Liu et al., 2022), leading to more active economic activities. The dual rural-urban imbalance is a major obstacle to the integration of economic development in most developing countries (L.-H. Li, 2017). Sheykhi (2016) proposed a state of development balance between rural and urban areas, in the absence of which both the rural and urban sectors would be vulnerable. Economic growth is closely associated with job creation. Globally, Kapsos (2006) found that for every 1-percentage point of additional GDP growth, total employment grew between 0.3 and 0.38 percentage points. Based on the above work, EC consists of four measurement items: industrialization level, urbanization level, balanced economic development of urban-rural areas, and share of employment.

Table 1. The measurement model for constructs[1]

Constructs	Measurement items	Related studies	Loading	t-value
DHP development level (DHP)	DHP.1: The construction and operation of our digital highway projects can **promote the development of information transmission and software technology**, thereby promoting economic growth along the route.	Qu and Pinsonneault (2022), Eicher and Strobel (2008)	0.903	51.717
	DHP.2: The construction and operation of our digital highway projects can **promote the development of the transportation industry**, thereby promoting economic growth along the route.	Lin (2019)	0.916	63.421
	DHP.3: The construction and operation of our digital highway projects can **promote the development of the scientific research and technology service industries**, thereby promoting economic growth along the route.	S. Yang et al. (2020)	0.905	45.784
Increased Transportation Demand (ITD)	ITD.1: The construction and operation of our digital highway projects can **increase the freight/passenger carrying capacity**, thereby promoting economic growth along the route.	P. Wang et al. (2018)	0.908	57.918
	ITD.2: The construction and operation of our digital highway projects can **improve traffic safety**, thereby promoting economic growth along the route.	Wu et al. (2015) and Yang et al. (2018)	0.821	20.899
	ITD.3: The construction and operation of our digital highway projects can **increase transportation information transmission**, thereby promoting economic growth along the route.	Peng et al. (2019) and J. Wang et al. (2018)	0.896	57.405
New Factor Endowment (RPF)	RPF.1: The construction and operation of our digital highway projects can **raise capital mobility**, thereby promoting economic growth along the route.	Zeng (2015), Grossman and Helpman (1990)	0.867	37.760
	RPF.2: The construction and operation of our digital highway projects can **raise human resources transfer**, thereby promoting economic growth along the route.	Vu (2011) and Myovella et al. (2020)	0.878	39.334
	RPF.3: The construction and operation of our digital highway projects can **raise advanced digital technology application**, thereby promoting economic growth along the route.	Vu et al. (2020), Chen and Mei (2018)	0.895	52.789
	RPF.4: The construction and operation of our digital highway projects can **raise transport data collection, and transmission capabilities**, thereby promoting economic growth along the route.	Ye et al. (2024)	0.822	26.311
The Development of Related and Supporting Industries (DI)	DI.1: The construction and operation of our digital highway projects can **prompt industrial clustering**, thereby promoting economic growth along the route.	Deng et al. (2013)	0.913	66.654
	DI.2: The construction and operation of our digital highway projects can **prompt industrial structure upgrading**, thereby promoting economic growth along the route.	Deng et al. (2013)	0.875	34.915
	DI.3: The construction and operation of our digital highway projects can **expand industrial scale**, thereby promoting economic growth along the route.	Tan et al. (2016), Du (2007)	0.915	61.826
Economic Growth (EC)	EC.1: Economic growth will help **promote industrial development along the route**.	Brahmasrene and Lee (2016)	0.884	42.167
	EC.2: Economic growth will help **improve urbanization level along the route**.	Brahmasrene and Lee (2016)	0.930	76.188
	EC.3: Economic growth will help **promote balanced urban-rural development along the route**.	Zhang et al. (2015)	0.878	38.099
	EC.4: Economic growth will help **improve the share of employment along the route**.	Moreno-Monroy et al. (2016) and Ren et al. (2021)	0.847	32.492

[1] Loadings and t-values of measurement items were the results of this study.

3.2. Data collection

Owing to the nascency of DHPs, the common use of panel data to verify their economic impact is limited. In this case, key stakeholders' perceptions can be exploited as the stakeholder theory emphasizes that businesses and institutions must balance the needs of multiple groups to achieve long-term success (Valentinov et al., 2019). For research, this theory provides a structured way to define boundaries and identify relevant actors and their interests by attaining key perspectives while avoiding unnecessary complexity (Jamali, 2008). Therefore, this study focused on surveying stakeholders of DHPs (e.g., those from the investors, construction and operations companies, and government regulatory departments) because they can intimately observe changes in DHP development, ITD, RPF, DI, and EC, thus aligning with our research questions. Additionally, these stakeholders were selected from projects that reached the operation phase because project performance (e.g., the impact on transportation demand) cannot be observed otherwise. As a result, 11 digital highway projects across 11 provinces in China that have been in operation were identified in Table 2 and their stakeholders were surveyed.

The questionnaire of the present study consisted of three parts. The first part was the description, including the purpose of the survey and an explanation of DHPs. The second part contained questions about the respondents' background information, including education, working years, type of company, and career experience of digital transformation. The third part measured the five latent variables using the measurement items listed in Table 1. To ensure effective responses, clear definitions of constructs were provided along with detailed instructions that guided respondents to give their answers. Before distribution, the questionnaire was scrutinized by three experienced experts in highway digital transformation. Two experts were from China's leading transportation infrastructure investment, construction, and operation companies while the other was a researcher working in infrastructure construction and operations at a well-known university. Their feedback led to improvements in the content and wording to maximize the comprehensibility and validity of the questionnaire, including rephrasing confusing items, merging overlapping items, and removing redundancies. Thereafter, a pilot study of 28 respondents was conducted (not included in the survey), and we further revised the descriptions of several items before the final questionnaire was administered using the "Questionnaire Star" platform (Si et al., 2020). During the survey, the respondents were encouraged to communicate with the researchers to resolve any perceived ambiguities in the measurement items. After confirming a common interpretation between the respondents and the researchers, the respondents were asked to evaluate their projects using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). This project-based method is more robust than individual data collection because it reduces potential biases from individual respondents representing an organization.

Data were collected from April 2023, to May 2023. Among the 11 identified projects (Table 2), respondents who had experience in the construction, operation, management, and digital upgrading of highway projects were purposively identified and contacted. As a result, 240 participants from five projects agreed to participate in the study. Stakeholders from the other nine declined to participate due to availability and commercial sensitivity reasons.

Table 2. Selected DHPs in China

Project name	Areas	Operation date
Changde-Changsha highway (Changyi part)	Hunan province	August, 2020
Shuangliao-Zhaonan highway	Jillin province	September, 2020
Tianjin-Shijiazhuang highway	Beijing-Tianjin-Hebei urban agglomeration	December, 2020
Shenzhen outer ring highway	Guangdong province	December, 2020
Chengdu-Yibin highway	Sichuan province	December, 2020
Beijing-Xiongan highway (Hebei part)	Hebei province	May, 2021
Wufengshan future highway	Jiangsu province	June, 2021
Shawu highway	Guangxi province	September, 2021
Hangshaotai highway (Shaoxing-Jinhua part)	Zhejiang province	February, 2022
Ezhou airport highway	Hubei province	May, 2022
Pingjiang-Yiyang highway	Hunan province	November, 2022

After a data cleansing process where responses completed with highly similar answers were abandoned, 198 valid questionnaires were finally adopted, corresponding to a response rate of 82.5%. Among them, the majority (35.9%) of the respondents were from highway investment companies, 24.7% were from the highway construction and operations departments, 17.7% were from government and research institutions, and 21.7% were the users.

3.3. Data analysis

A variety of methods have been adopted to examine the relationships between variables, including Bayesian models, Covariance-based Structural Equation Modeling (CB-SEM), and Partial Least Squares Structural Equation Modeling (PLS-SEM). PLS-SEM was chosen to test the hypotheses of our study due to the following reasons. First, Bayesian models and CB-SEM emphasize theoretical verification by confirming the relationship between various factors based on established theories. As affirmed by Hair et al. (2011, 2017, 2019) PLS-SEM is considered appropriate for confirmatory or exploratory research. Our study is more of an exploratory nature as we focus on discovering new relationships, new dimensions and applications of existing theories. In our study, the measurements are new (i.e., the measurement items of DHP, ITD, RPF, DI, and EC in Table 1) and their relationships have not been previously tested. Meanwhile, we seek to explore the extension of regional competitiveness theory in the digital context to deepen the understanding of how DHPs contribute to economic development. In this sense, PLE-SEM is particularly advantageous for our exploratory study following a similar approach in Buitrago et al. (2024). Second, PLS-SEM can handle complex interrelations among many constructs and items without requiring a large sample size, which may otherwise not possible in CB-SEM (Urbach & Ahlemann, 2010). Hair et al. (2011) propose the '10-times rule' in determining the minimum sample size in PLS-SEM. Given five constructs in our research model, the minimum required sample size to test our model using PLS-SEM is 50. A sample size of 198 responses from 14 case DHPs is, therefore, appropriate to test the model using PLS-SEM (Hair et al., 2011). Third, PLS-SEM has the advantage of analyzing data without the assumption of a normal distribution. According to Reinartz et al. (2009) and Sarstedt et al. (2016), CB-SEM could generate abnormal results with a small sample size due to the possibility of a non-normal distribution of data whereas PLS-SEM remains to be robust. On this basis, PLS-SEM, consisting of the principal component analysis, path analysis, and regression analysis to evaluate theory and data (Ringle et al., 2012), was utilized to validate the measurement model (Table 1) and test the hypotheses (Figure 1).

The data analysis was conducted in two stages using the SmartPLS 3.0 software package. First, we examined the reliability and validity of the measurement model. Second, we tested the hypothesized relationships between the latent variables. Owing to the non-normal distribution of the data in PLS-SEM, a nonparametric bootstrap procedure was employed to test the statistical significance of the path coefficients (Hair et al., 2011). For this study, bootstrapping utilized 198 samples, with 5000 random resamples and a confidence interval (CI) of 95%. We now present results of the two stages.

4. Results

4.1. Reliability and validity analysis

The reliability and validity of the measurement model were assessed based on[2]: (1) indicator reliability; (2) internal consistency; (3) convergent validity; and (4) discriminant validity (L. Wang et al., 2020). All measurement items had factor loadings and t-values over 0.6 and 2.58, respectively (the last two columns of Table 1), which exceeded the threshold of indicator reliability stated in (Hair et al., 2011). Cronbach's α and Composite Reliability (CR) both exceeded 0.7 (Table 3), which suggested acceptable internal consistency within each latent construct (C. Zhang et al., 2019). The Average Variance Extracted (AVE) values exceeded the 0.5 threshold, indicating sufficient convergent validity. Moreover, the Fornell-Larcker criterion verified the discriminant validity (Hair et al., 2011), as the square root of the AVE for each latent construct exceeded its correlation with any other latent construct (Table 4). In summary, the results indicated that the addition of a measurement model (Table 1) was reliable and valid.

Table 3. Reliability, internal consistency, and convergent validity of the measurement model of constructs

Constructs	Cronbach's α	CR	AVE
DHP	0.894	0.894	0.824
ITD	0.848	0.865	0.767
RPF	0.888	0.888	0.750
DI	0.884	0.888	0.812
EC	0.907	0.910	0.783

[2] Indicator reliability verifies the reliability level of individual indicators (observable variables) in measuring the latent constructs. Internal consistency is a measure of the reliability of a set of items (e.g., survey questions or test items) that are intended to assess the same construct. Convergent validity can be used to verify that different measurements can effectively capture the essential characteristics of a construct. Discriminant validity verifies whether measurements can effectively distinguish between different constructs.

Table 4. Results of the Fornell-Larcker criterion

	AVE	EC	DI	DHP	RPF	ITD
EC	0.783	**0.885**				
DI	0.812	0.665	**0.901**			
DHP	0.824	0.699	0.842	**0.908**		
RPF	0.750	0.747	0.856	0.836	**0.866**	
ITD	0.767	0.626	0.830	0.814	0.859	**0.876**

Note: The bold numbers are the root of AVE, and the lower triangle is the Pearson correlation.

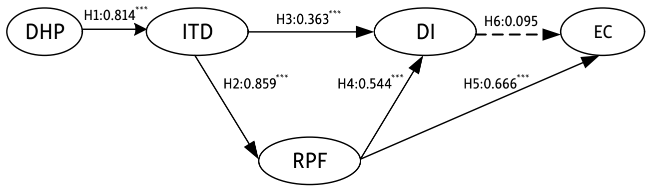
4.2. Hypotheses testing

The determination coefficients (R^2) serve as the evaluation criteria for the structural model. R^2 is a measure of the model's predictive accuracy and explains the variation in the latent variables. According to Hair et al. (2011), an R^2 value more than 20% for the dependent variable suggests that substantial variance in the construct is explained by the research model. In our study, the structural model accounted for 66.3% of the variance in ITD, 73.8% in RPF endowment, 76.7% in DI, and 56.0% in EC, indicating that the structural model has significant explanatory power for changes in variables.

Path coefficients, significance levels, and Confidence Intervals (CI) are presented in Figure 3 and summarized in Table 5 where most hypotheses are supported, except for H6. Specifically, DHP has significant positive effects on ITD (H1: $\beta = 0.814$, $p < 0.001$); therefore, H1 was supported. ITD positively influences RPF (H2: $\beta = 0.859$, $p < 0.001$) and DI (H3: $\beta = 0.363$, $p < 0.001$), supporting H2 and H3. The results for RPF showed a positive effect on DI (H4: $\beta = 0.544$, $p < 0.001$), supporting H4. EC is positively influenced by RPF (H5: $\beta = 0.666$, $p < 0.001$), but not by DI (H6: $\beta = 0.095$, $p > 0.05$), supporting H5 but not H6.

Table 5. Test results of hypotheses

Hypothesis	Standardized coefficient	t-value	CI		Results
			2.5%	97.5%	
H1: DHP development level (DHP)→Increased transportation demand (ITD)	0.814	24.215	0.740	0.872	Supported
H2: Increased transportation demand (ITD)→New factor endowment (RPF)	0.859	36.456	0.808	0.900	Supported
H3: Increased transportation demand (ITD)→The development of related and supporting industries (DI)	0.363	3.984	0.188	0.545	Supported
H4: New factor endowment (RPF)→The development of related and supporting industries (DI)	0.544	6.071	0.361	0.712	Supported
H5: New factor endowment (RPF)→Economic growth (EC)	0.666	6.825	0.483	0.864	Supported
H6: The development of related and supporting industries (DI)→Economic growth (EC)	0.095	0.834	–0.137	0.304	Not Supported



Note: ***p < 0.001 (t > 3.29), **p < 0.01 (t > 2.58), *p < 0.05 (t > 1.96).

Figure 3. Path coefficients and significance of the final model

5. Discussion and implications

5.1. Discussion

As Figure 3 illustrates, the coefficients (β = 0.814, p < 0.001) of H1 indicates that the development of DHPs positively and directly affect Transportation Demand (ITD). Intuitively, upgraded roads can easily meet original travel demands and dilute existing traffic (W. Chen & Klaiber, 2020). However, according to the "induced demand" theory, travel demand increases exponentially with widened roads and leads to more congestion (Hymel, 2019). Similarly, Garcia-López (2019) found that highway construction induces traffic almost proportionally in Europe. These studies attributed traffic congestion to increased traffic capacity brought by road construction. Our study further indicates that DHPs increase transportation demand, including not only increased traffic volume, but also improved traffic safety and accelerated data transmission efficiency. Specifically, unlike traditional highways, DHPs (e.g., road operation monitoring platforms and intelligent service areas) can improve road emergency management capabilities and user experiences, thereby inducing additional vehicle travel. Real-time transmission of road information, enabled by wireless communication technology, allows smooth communication between vehicles. Information fusion technology integrates data from different sensors, which decreases travel congestion and attracts new traffic. The digital improvement of road functions further spurs travel activities along corridors (Cervero, 2003). Therefore, developing DHP is likely to induce new traffic, which can offset some anticipated traffic reduction benefits of highway digital upgrades (Cervero, 2003).

According to coefficients (β = 0.859, p < 0.001 and β = 0.666, p < 0.001) of H2 and H5, we also verify that ITD can indirectly impact Economic Growth (EC) via new factor endowment (RPF). This finding coincides with Banerjee et al. (2020), Pu and Qiu (2014), and S. Wang (2016), where they argue that highway projects increase transport capacity and then facilitate labor migration, cross-regional capital investment, and new technology sharing. For instance, road infrastructures expand metropolitan labor markets by job redistribution, thus prompting production efficiency (Brugnoli et al., 2018). Notably, our results also highlight data flow as a new factor endowment (RPF) enhancing economic growth. This is because, the tests of reliability (Cronbach's α = 0.888), internal consistency (CR = 0.888), and convergent validity (AVE = 0.750) in Tables 3 and 4 validate RPF's measurements and H5 is further supported (β = 0.666, p < 0.001), thereby proving that as one of the four measurements for RPF (Table 1), transport data flow can contribute to economic growth. That is to say, we reveal that DHPs induce increased transportation demand, and then promoted the transmission and analysis of transportation data resources (Babar & Arif, 2019; Dabiri & Heaslip, 2018; R. Liu et al., 2025), which was not previously available in traditional transport projects (Banerjee et al., 2020; Pokharel et al., 2021). Specifically, real-time data on speed empower travelers to navigate their routes effectively and make informed decisions by fostering cooperation between cross-regional traffic departments, therefore driving forward the economic efficiency. As such, our findings empirically supplement growth theories by including the transportation data flow in the digital economy era. This is because a new growth theory should be continuously developed by adding new endogenous and exogenous factors (Grossman & Helpman, 1990). In fact, the equilibrium models by Cai et al. (2022) and Jia et al. (2023) suggest that the economic growth rate after the introduction of data elements is consistently higher than before.

Another finding emphasized by our study (H3: $\beta = 0.363$, $p < 0.001$) is the positive effect of ITD on the development of related and supporting industries (DI), which is supported by B. Sun et al. (2017) and Chang et al. (2021). The possible explanation is that expanding freight/passenger carrying capacity promotes industry agglomeration by strengthening cross-regional trade activities (Lin, 2019; Melo et al., 2016). Meanwhile, the increased transportation demand necessitates robust support from various digital technologies, thus prompting the growth of knowledge-intensive digital industries (B. Wu & Yang, 2022). Our study further shows that ITD has a stronger effect on RPF (impact coefficient of 0.859) than that on DI (impact coefficient of 0.363). Although previous studies have explored the individual impact of transportation infrastructure on factors endowment (Makhlouf & Helali, 2024; Paaswell, 2010; Yang et al., 2022) and related industrial development (Chang et al., 2021; B. Sun et al., 2017), the promotion effects between these two factors have not been compared. The stronger effect on RPF demonstrates that efforts to increase transportation demand are more likely to lead to a large expansion of factors endowment to develop related industries. This finding supplement that if the new factor endowment can be fully utilized, it will be viewed as more beneficial.

Furthermore, the coefficients ($\beta = 0.544$, $p < 0.001$) of H4 indicated that RPF, including technologies, labor, capital, and data flow, were found to have significant positive effects on DI. This finding is consistent with N. Chen et al. (2022) to show that the premise for the development of the digital industry seems to be characterized by rapid growth in both labor and capital productivity. Digital industry seems to be of the labor-saving kind, and thus, labor productivity growth can be more likely to improve industry productivity. The increase in capital results directly from the labor-saving tendencies in technological change. Meanwhile, Lee and Oh (2020) and Soete (1985) claimed that the international diffusion of technology has been a major factor behind industry development. These demonstrate that the development of new factor endowment is a priority for digital industry. In addition to digital industry, Portes and Benton (1984) also found that the growth in other modern industries was based on the agglomeration of labor force.

Besides, according to coefficients of H6 ($\beta = 0.095$, $p > 0.05$), it is worth noting that DI fails to significantly influence EC both directly and indirectly. These findings diverge from previous studies conducted for traditional road projects, which suggested that "reduced physical distance" promotes industrial co-agglomeration and contributes to growth (Lin et al., 2019; Melo et al., 2016; Nurlestari & Oktavilia, 2023; C. Peng et al., 2022; Widodo et al., 2014). Considering digital technologies and the "data channels", the possible explanation for these insignificant effects of DI may include two aspects (Lee & Yoon, 2021; J. Wang et al., 2022). First, as the development of DHPs in developed regions significantly outpaces undeveloped regions, the industrial development gap is exacerbated and then the synergistic effects of regional economic growth are hindered. Specifically, regions with advanced DHPs are better positioned to foster industrial agglomerations reliant on efficient logistics, such as equipment manufacturing and electronic product assembly (H. Zhang et al., 2025). They also support lean production in high-end manufacturing sectors like automotive and aerospace components and cultivate e-commerce clusters in areas such as smart logistics and cold chain logistics (Y. Sun et al., 2020). In contrast, regions with underdeveloped DHPs, constrained by inefficient transportation and logistics, tend to prioritize industries that leverage local resource endowments over those dependent on transportation, such as resource-intensive industries, eco-tourism, and cultural enterprises. This imbalanced industrial distribution, coupled with the fragmentation of industrial chains across regions, leads to the uneven allocation of resources – capital, labor, and technology – thereby restricting economic diversification and diminishing production efficiency (Tao Yang & Zhou, 1999). As a result, the economic growth effects remain limited and lack significant impact. Second, it takes some for DHP-related digital industries to promote economic growth. Specifically, in the short term, emerging industries tend to bear higher costs due to substantial technological research and development expenditures. Meanwhile, given the relatively small production scale at this stage, these industries are unable to harness the benefits of economies of scale, resulting in elevated unit product costs.

Finally, our study suggests that a causal path exists starting from the developing DHP, but mediated through ITD and RPF, and ultimately to EC. In other words, the development of DHP will lead to economic growth through complex transmission mechanisms, beyond the development of DHP itself. The maximum utilization of factor endowment may be the priority consideration for government when developing DHP. Specifically, in addition to enriching the road network structure to promote the flow of traditional production factors, the layout of the DHP should also facilitate the collection, analysis and retrieval of traffic data flow (Giudici & Pérez-Fortes, 2022).

5.2. Theoretical implications

This study makes several important theoretical contributions. First, based on the digital characteristics of DHP, this study further develops the regional competitiveness theory. Four competitiveness factors, namely DHP development, increased transportation demand, new factor endowments, and the development of related and supporting industries, were developed. Previous studies often emphasize competitiveness in terms of corporate strategy, domestic demand condition, traditional production factor, and related and supporting industries. While there are similarities, digital advantages should also be integrated into regional competitiveness since technology innovation and transport data flow can further expand the competitiveness. Specifically, this study differs from the previous competitiveness by introducing new measurements into the four new competitiveness factors, particularly regarding increased transportation demand about a higher safety level and more real-time traffic data transmission, data-based factor endowment, and technology-based industry upgrading. This can enhance the conceptual understanding of competitiveness factors to make the regional competitiveness theory more comprehensive. Our findings also provide empirical evidence for the complex cause-and-effect relationship between these competitiveness factors and economic growth.

Second, the concept of the induced demand effect was demonstrated by analyzing the relationships between developing DHP and increasing traffic demands. Based on the induced demand theory, price reduction and quality improvement of goods can attract more consumers. Similarity, scholars in the field of traditional mode of transportation have suggested that road capacity expansion is a key to inducing more traffic flow (W. Chen & Klaiber, 2020). Despite the increased transport demands in DHPs, this increase is mainly because of enhanced information processing capabilities and traffic safety through data sharing and integration. In this sense, our results complement the induced demand theory by suggesting that improved traffic safety and accelerated traffic information transmission should also be considered as induce causes for the increase in traffic volume.

Finally, our findings on the influences of new factor endowment on economy complement growth theory to some extent. Previous studies have verified the positive effect of labor, technology, and capital on growth based on the exogenous and endogenous theory (Lucas, 1988; Solow, 1956). However, a limited number of studies have included data resource in the growth framework and empirically tested its causal relationships with economic growth. In contrast, our study makes strides in providing empirical evidence for including data flow factors in the growth theory, which supports the view that DHP practices should evolve with technological changes and data flow (Chinoracky et al., 2021). In the increasingly digitalized transportation industry, our findings acknowledge the advantages of data flow and, hence, contribute to growth-related research in the digital economy era.

5.3. Policy implications

This study can help policymakers understand how to effectively promote economic growth by developing DHP. First, the government should pay attention to the factor endowment brought by DHP development because it is a critical node on the influence paths (H5: 0.666, $p < 0.001$). Specifically, policymakers should prioritize increased transportation demand and new factors endowment as a promising approach for economic growth via DHP development. An effective transmission of data flow, as a new factor endowment, helps predict road conditions and optimize driving routes, thereby motivating the cross-regions diffusion of labor, capital and technology. Therefore, policymakers should deploy data-related technologies efficiently (Lythreatis et al., 2022). Specifically, for data with high access frequency and ultralow latency including autonomous driving, a more relevant digital infrastructure (e.g., edge computing base stations) should be constructed around roads (Caiazza et al., 2022). The off-site technology can handle data with low access frequency and high latency, including highway disaster recovery data. Second, the government should consider whether the labor transfer, capital flow and technology diffusion efficiency brought about by DHP are matching with the local economic level. Due to their high demand developed regions should further develop DHP (such as, Shenzhen outer ring highway and Wufengshan future highway) to promote economic efficiency, while developing DHP in undeveloped areas may increase the government's investment burden.

Second, policy makers may not pay too much attention to the development of related and supporting industries (DI) as our study demonstrates an insignificant coefficient in the early stages of DHPs' operation (H6: 0.095, $p > 0.05$). Our findings suggest that such efforts may result in the inappropriate deployment of DHPs and insignificant growth, hindering the positive effects of DHPs on economic efficiency. However, this insignificant effect is likely to be short-term due to the time-lag effect of DHP-related digital industries on economic growth (Akpan & Eweke, 2017). Given the imbalanced industry structure across regions, this could also mean that undeveloped regions need to be prioritized by governments for policymaking. An actionable way is engendering policies to encourage cross-province/state investments to expand digital facilities in the undeveloped regions, e.g., leveraging the private entities' or public authorities' capitals from DHP-developed regions.

Third, since this study emphasized digital characteristics of highways to reflect their new competitiveness in regional economic growth, which are different from traditional highways, the awareness of digital technologies and individuals' application level of them should be improved. Governments are expected to enact effective policies to encourage digital literacy of stakeholders in different regions. The improvement of digital literacy can relieve the digital divide between individuals, communities, or nations in terms of the access to and use of digital technologies, especially for cutting-edge transportation technologies, thereby balancing economic opportunities, education, healthcare, and social participation.

6. Conclusions

In the era of digital economy, DHP are driving economic development in new ways. This study developed a theoretical model underpinned by six hypotheses (H1 – H6) to explore causal links between DHP and economic growth. This research used empirical data collected from experienced stakeholders and analyzed the data using the established PLS-SEM. Extending the regional competitiveness theory, this study developed new competitiveness advantages of DHP to grow regional economy. Meanwhile, the reliability and validity analysis showed that the measurements for each construct was reliable and valid, including the development of DHP, increased transportation demand, new factor endowments, and the development of related and supporting industries. Specifically, H1 – H5 of the theoretical model were supported while H6 was rejected. Addressing the first research question, this highlighted that these interacting factors contribute to economic growth via a path, commencing from DHP development, mediated by increased transportation demand and new factors endowment, and ultimately leading to growth. Moreover, the results indicated that DHP development significantly increases new transport demand, which supplement explanations for the induced demand theory in the transportation field. Increased transport demands not only raise factor endowments (i.e., capital, labor, technologies, and data flow) but also have a significantly direct impact on developing related and supporting industries (i.e., industrial cluster, industrial structure upgrading, and industrial scale). The positive effect of new factor endowments on economic growth is significant by verifying the growth theory. However, developing related and supporting industries statistically insignificantly impacts growth. As a result, the second research question was addressed as effective and targeted recommendations; for instance, efficiently deploying data-related technologies and improving diffusion efficiency of factor endowment are provided to guide the DHP development and economic growth.

This study has several limitations that open avenues for future research in the domain of DHP development and regional economic growth. First, the relationships among influencing factors were simplified as linear by using PLE-SEM, but it may risk oversimplifying the actual complexity of these interactions. Future studies can undertake a simulation analysis to explore the nonlinear effects of DHPs on growth from the spatiotemporal heterogeneity perspective. Second, based on China's evidence, we collected data from stakeholders of its DHPs and deployed PLS-SEM. For countries/ regions with limited macro data, such data collection and analysis method can also be applied to provide an understanding of the impact mechanism of digital infrastructure projects on economy. Third, although we have unpacked the impact mechanism among DHP, ITD, RPF, DI and EC from the perspectives of stakeholders and the regional competitiveness theory, future studies in different regions can consider control variables to explore individual variable's (e.g., ITD and other variables) impact on EC and this can benefit from objective data (e.g., GDP) when available. Forth, our research adopted a cross-sectional survey design. Since the digital technologies adopted in highway projects may evolve over time, future research can apply longitudinal methods (e.g., longitudinal case studies) to examine the long-term impact mechanism of DHPs on economy. For instance, as DHPs in China only began to enter into operation, the knowledge encapsulated within our data sample is likely to be limited. This could mean that although the relationship between DI and EC (H6) was not significant in this study, its long-term effect(s) remains to be tested. Nonetheless, this study acts as a 'trailblazer' to inform policymakers around the globe of the role of DHPs in regional economic growth.

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Author contributions

Rui Liu: conceptualization, data curation, formal analysis, software, funding acquisition, methodology, writing – original draft. Jingfeng Yuan: conceptualization, data curation, formal analysis, software, supervision, funding acquisition, methodology, writing – review & editing. Guangdong Wu: methodology, supervision, Writing – review & editing. Jianfeng Zhao: formal analysis, methodology, writing – review & editing, supervision. Bingsheng Liu: conceptualization, funding acquisition, supervision.

Disclosure statement

The authors declare that they have no competing interests.

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