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Research paper

# Robotaxi service: The transition and governance investigation in China

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ABSTRACT

The Multi-Level Perspective (MLP) views transition as a process resulting from the interaction of social and technological factors at different levels. With the MLP approach, the robotaxi service transition and governance driven by autonomous driving technologies are investigated based on the current development of China. We divide the transition of robotaxi service into four phases: The first phase (1991–2015) shielded the innovation of robotaxi by determining legal status; Governments, enterprises, universities, and industry consortia conduct autonomous driving trials and advance the adoption of technologies in the second phase (2016–2025); The third phase (2026–2035) would aim to tackle barriers in regulation, industry and public acceptance, and enhance competitiveness of the robotaxi to enter the market; The fourth phase (2036–2050) would form the robotaxi based service system. We found urbanization process and the innovation-driven economic shift, low-carbon development, and aging population have created a favorable landscape "pushing" for the development of robotaxi service. With the current transition in the second phase, the central government, local governments, and enterprises could tackle obstacles in regulation, economy, and public attitude to build a suitable environment for the robotaxi service development. Moreover, the robotaxi service towards the mobility as a service (MaaS) business model is also discussed to develop an integrated mobility ecosystem.

## 1. Introduction

Taxi service, dominated by traditional cruising taxis, has been regarded as a part of urban mobility service systems. In recent years, there have been witnessed a spurt of progress in sharing mobility services and digital technologies, which have brought the rise of emerging shared mobility services, e.g., car sharing, online car-hailing, demand-responsive transit, etc. Online car-hailing services (OCS) have flourished and impacted traditional taxi services (TTS), starting the transition of taxi service in China. However, the incremental changes within the taxi service regime are insufficient to meet the severe challenges of landscapes, e.g., energy shortages and carbon emissions, urban expansion, and aging populations. The development of autonomous vehicles (AVs), which integrates a series of disruptive technologies, sets to trigger a profound and transformative sociotechnical transition within the automotive industry, akin to the transition from horse-drawn carriages to automobiles (Skeete, 2018). Not only will it make existing modes of mobility, such as cars, taxis, and public transport, more attractive by reducing travel costs, but it will also enable the emergence of new modes, vehicle types, and ownership concepts (Cervero, 2017). Robotaxi, an autonomous operating taxi, is currently one of the leading applications in urban mobility services based on AVs. Countries worldwide have also provided autonomous services to their intelligent transport development strategies. Companies such as Waymo, Google, Lyft, Baidu Apollo, and AutoX, are carrying out robotaxi development and commercialization.

Taxi service systems as a sociotechnical system, cover technology and infrastructure, policies and regulations, markets and practices, culture and public perception, and the industries involved in production and operation. This transition requires a coordinated development of technological advances and lots of social factors. The development of AVs would drive the transition of the mobility service system. Most existing studies have been focusing on technical factors and lack an in-depth conceptualization of the complex multi-level forces that impact upon transition. The introduction of AVs driven solely by technological and commercial developments may ignore the sociotechnical nature of the mobility system. It may conflict with planning objectives such as reducing negative externalities of motorized transport and developing a healthy and socially inclusive mobility system (Fraedrich et al., 2019; Milakis, 2019).

There are some existing empirical socio-technical transition studies based on MLP, such as different applications in mobility system

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transitions, for example, the transition toward low-carbon mobility (Canitez, 2019; Geels, 2018; Köhler et al., 2020; Van Sluisveld et al., 2020), the transition towards multi-modal urban mobility (Spickermann et al., 2014), the transition towards mobility as a service (Hirschhorn et al., 2019), towards automotive sustainability (Cohen, 2012), and the transition towards electro-mobility (Berkeley et al., 2017; Mazur et al., 2015). Moreover, there have been some studies of AV-driven socio-technical transitions. For example, Whittle et al., 2019) integrate insights from the multi-level perspective (MLP) on transitions, and socio-psychological literature and draws on expert interview data to examine factors influencing current attitudes and behavior towards Electric vehicles (EVs), AVs, and shared mobility. Marletto (2019) uses sociotechnical maps representing urban mobility in the year 2040 to represent the potential results of three transition pathways toward AVs, each being led by different innovators. Hansson (2020) develops an analytical model based on regulatory governance theories and argues that regulatory design may need to be more flexible to accommodate uncertainty and the rapid pace of technological evolution. Milakis and Müller (2021) present a research agenda that contributes to rebalancing the focus from the technical to the societal dimension of the AVs transition. Turienzo et al. (2022) predict the impact of AV and shared mobility development on the mobility service system. However, there are still some research gaps. For example, few existing studies have focused on the transition pathways according to the temporal dimension, and most existing studies focus only on ongoing case studies at the large scale level. Moreover, existing studies lack of the co-evolution of AVs and mobility service systems and rarely consider them in specific application scenarios.

Based on the MLP approach, this study has involved the transition process of robotaxi service in China, and the following research questions are highlighted:

1. What are the driving forces that drive the transition?
2. What are the expected obstacles for transition, and how might they be addressed?
3. What is the expected governance focus at each phase of the transition?

The remaining sections of the paper are organized as follows. Section 2 describes the MLP approach, data sources, and research methodology. Section 3 divides the transition into four phases, analyses the drives and barriers to transition and governance focus, and investigates how the development and diffusion of robotaxi services relate to the roles of markets, governments, managers, and the public. Section 4 discusses regime actors within the robotaxi service system towards the mobility as a service (MaaS) business model to develop an integrated mobility ecosystem, and Section 5 concludes.

## 2. Material and methodology

Premised on a non-linear conceptualization of evolutionary processes, the MLP integrates the complex dynamic innovation processes achieved by interacting social factors and/or technological innovation into an analytical framework, which explains the transition process. Transition results from the interaction of multiple level developments at three levels, i.e., niche, regime, and landscape (Geels & Schot, 2007). Most innovations and complex changes emerge in the niche, and low-performance levels and unstable socio-technical configurations characterize their initial phases. The regime is a coherent and interconnected structure of established and formed products, technologies, knowledge stocks, user practices, standards, regulations, etc. Existing socio-technical regimes shape and stabilize existing technological pathways by interacting with their constituent elements, i.e., creating path dependency and lock-in effects (Geels, 2010). The landscape encapsulates the socio-technological settings, such as the social environment, macroeconomic patterns, demographic trends, political ideologies, and social values.

As illustrated in Fig. 1, the process of socio-technical transition based on the MLP approach is generally manifested as follows. Changes in the landscape would put pressure on the existing regime providing a window of opportunity for the niche to emerge. When the niche develops to a certain extent, it would develop a strong resource allocation capacity and institutional influence to counteract the existing regime, thus destabilizing it. When the existing regime cannot adapt and resist the increasing pressure from the landscape and niche, technological transition and institutional change would eventually occur, and a new socio-technical regime would emerge and influence the landscape (Geels, 2002). This process can be divided into four dynamic phases: radical innovation emergence, innovation formation and stabilization, widespread proliferation and breakthroughs (Geels et al., 2017).

In this study, we intend to analyze the transition of robotaxi service in China. As shown in Fig. 1, we have divided the transition into four phases. The primary landscape pressures and their potential impact on the regime are first highlighted for each phase. Then, we sort out the dynamic development of the existing regime from the perspective of technology, market, policy, and public preference. In the first and second phases, we focus on analyze the drivers of transition, and in the third and fourth phases, we focus on exploring the obstacles to transition and proposing solutions. The interactions between technological developments and actors are further investigate at the niche level. Note that robotaxi service refers to the individual or pooled taxis services in this paper, where individual taxis service refer to providing car-hailing service without human drivers, whilst pooled taxis refer to providing shared mobility service, where passengers share the robotaxi for at least part of the trip (Becker et al., 2020).

This study has been conducted to obtain relevant data and information from three primary sources. Firstly, government departments such as The State Council of the People's Republic of China, the National Development and Reform Commission, and the Ministry of Transport have issued development plans related to AVs. Secondly, statistics, reports, and yearbooks are published on official websites, such as the National Bureau of Statistics of China and the Sharing Economy Research Centre of the National Information Centre of China. Thirdly, reports are published by authoritative academic organizations or industry alliances in China, such as the China Association of Automobile Manufacturers. Moreover, this study benefits from an expert interview relating to governance of AVs and sustainable mobility in China, which has been carried out from March 2020 to April 2021. This interview aims to contribute to understanding how governance approaches could influence the introduction and use of AVs and the potential implications for sustainable mobility. We would like to understand what actors think might happen: so how they think governance may work and what the implications would be. Also it would be good to understand what recommendations they would make for governance. The interview is planned to invite around 9 senior practitioners involving AV development in China, and finally 9 interviewees are interviewed, which includes government official, senior staffs working on autonomous driving industry, and faculties working in the AV fields, as shown in Table 1.

## 3. Four transition phases for China's robotaxi service

We divide the transition of robotaxi service in this study into four phases. The first phase, i.e., radical innovation niche emergence, from the implementation of China's "Eighth Five-Year Plan" (1991–1995) in 1991, when autonomous driving entered China's critical defence pre-research program, to the release of China's first top-level design document on autonomous driving, "Made in China 2025". Further, The Chinese government released the "Strategy for the Innovative Development of Intelligent Vehicles" in 2020. It declares that conditional AVs (L3 AVs) would reach large-scale production, and advanced AVs (L4 and L5 AVs) would be marketed and applied in specific scenarios by 2025. It is expected that the Chinese standard intelligent vehicle system would

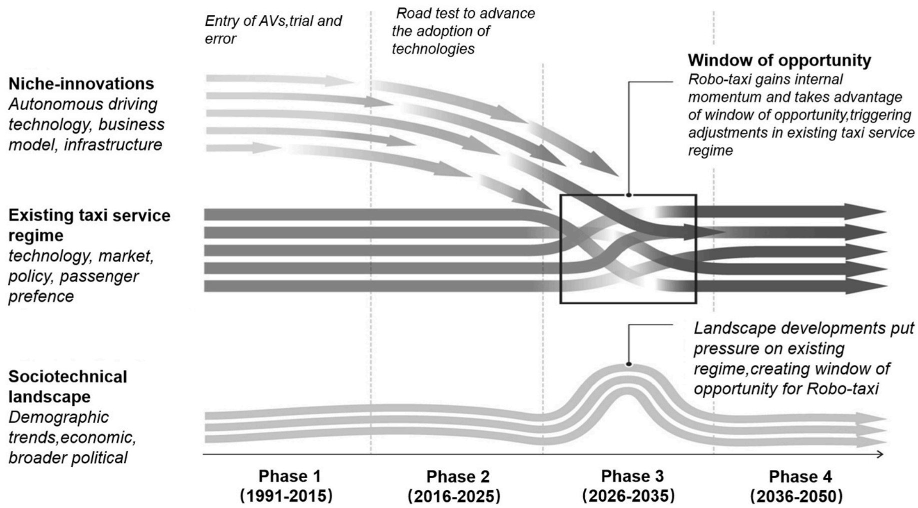


**Fig. 1.** Interaction of the three MLP levels in the China' transition for robotaxi service.
Source: Adapted from Geels et al. (2017).

**Table 1**
Characteristics of experts interviewed.

| Interviewee | Organization | Field/Research interest |
|---|---|---|
| 1 | University | Public policy and collaborative governance |
| 2 | University | Transportation data analytics and public transit system modelling |
| 3 | University | Transport network modelling and public transport |
| 4 | Technology company | Traffic safety and AV operation safety |
| 5 | University | AV's motion planning, driver behaviour, and traffic simulation |
| 6 | International organization | Automotive and Autonomous Mobility |
| 7 | University | Shared mobility on demand, and intelligent transportation systems |
| 8 | Technology company | Intelligent transportation system |
| 9 | University | AV operations management |

be fully completed from 2035 to 2050. According to the document, the second phase (2016–2025) is the stage of innovation formation and stabilization. The innovation niche is the widely diffused stage in the third phase (2026–2035). Moreover, the fourth phase (2036–2050) would achieve the stabilization and institutionalization of a robotaxi-based taxi service system. Fig. 2 selects the niche level, i.e., robotaxi service, and visualizes the relationship between technology development, market share, and transition phases. Moreover, the technical development indicator, i.e., automation levels, is based on the "Taxonomy of Driving Automation for Vehicle" released by the Chinese government in 2020.Table 2 shows the details of the Technical Standards.

### 3.1. Phase 1 (1991–2015):Emergence of radical innovation

#### 3.1.1. Landscape level

In the first phase, China's mobility system is under multiple pressures from the landscape. There are common international pressures, such as the world financial crisis in 2008 and the economic contraction that led to energy security issues coming to the fore. The transport sector accounts for a third of the world's energy consumption, and carbon reduction and energy efficiency are severe challenges for the transport

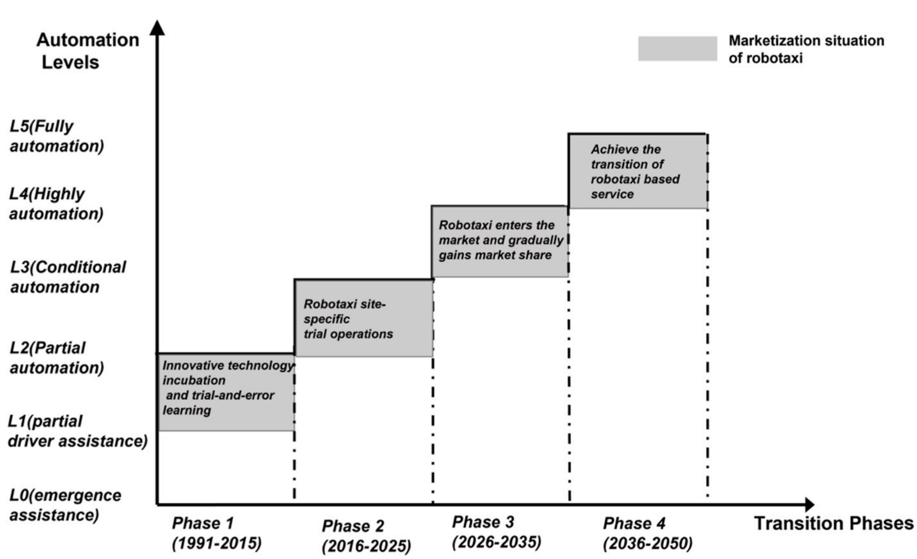


**Fig. 2.** Four transition phases for robotaxi service of China.

**Table 2**
Taxonomy of driving automation for vehicle.

| Level | Title | Vehicle motion control | Object and event detection and response (OEDR) | Dynamic driving task(DDT) | Operational design condition (ODD) |
|---|---|---|---|---|---|
| Level 0 | Emergency assistance | Driver | Driver and system | Driver | Limited |
| Level 1 | Partial driver assistance | Driver and system | Driver and system | Driver | Limited |
| Level 2 | Combined driver assistance | System | Driver and system | Driver | Limited |
| Level 3 | Conditional automated driving | System | System | DDT fallback-ready user | Limited |
| Level 4 | Highly automated driving | System | System | System | Limited |
| Level 5 | Fully automated driving | System | System | System | Un-Limited |

Source: National Technical Committee of Automation Standardization of China, 2020.

industry. It is estimated that urban transport account for approximately 25% of CO2 transport emissions contributing to climate change, almost entirely attributable to road transport, 58% of which comes from passenger transport (Nielsen, 2013).It also faces pressures specific to China, since the goal of establishing a socialistic market economy system has set since 1991, which forms a new milestone in the development of China's urbanization construction. The urbanization rate in China has proliferated, from 26.94% in 1991 to 56.1% in 2015 (National Development and Reform Commission of the People' s Republic of China, 2020). In terms of economic development during this period, the high-carbon economic development pattern is restrained seriously.

### 3.1.2. Regime level

The sudden urbanization corresponds to environmental deterioration and severe traffic congestion. China's government has adopted transportation demand management measures to restrict the ownership of private cars, resulting in bottlenecks in the growth of urban car ownership (Xu et al., 2017). As a complement to urban public mobility, traditional cruising taxi provides a door-to-door mobility service for passengers. However, the requirement for market access, quantity control, and price regulation of traditional taxis have led to slow growth in the number. As illustrated in the following Fig. 3, the total number of passengers served by taxi raised fast during 2008–2015, whilst the number of taxi operations increased slowly. It caused a severe conflict between supply and demand and problems such as expensive fares and the difficulty of taxi rides. Although the taxi service regime still has substantial stability, several cracks appear. As the innovation niche is not yet fully developed and landscapes generate moderate pressure, regime actors would respond by modifying the direction of development paths and introducing disruptive innovation (i.e., online car-hailing) to adapt to the pressures of the landscape. Online car-hailing services (OCS) can be adopted as competence-enhancing add-ons in the existing taxi service regime to ameliorate problems. Therefore, OCS have symbiotic relationships with traditional taxi services (TTS) in the process of transition. The OCS provided by some internet companies in the mobility sector in China, e.g., Yidaoyongche, was established in 2010. From then on, there was a proliferation of online car-hailing companies represented by Didi and Uber. In addition, it has also attracted internet technology companies and automakers to join the market.

Factors such as technology, markets, policy, and public acceptance etc., significantly influence socio-technical development. Firstly, from the perspective of technological development, innovations in big data technology have improved the efficiency of matching supply and demand and reduced the operating costs of taxi services. Internet technology has enabled on-demand response and online payment, improved mobility services' convenience and stimulating demand. Secondly, the stable economic environment has made financial capital active in the economic market. Capital has accelerated the development of emerging mobility services and attracted more talent and resources to enter, creating explosive growth. Based on sharing economy, online car-hailing temporarily transfers the use of vehicles and socializes the factors of production, providing efficiency in using stock assets, creating value for passengers, and contributing to the sustainable transition of the mobility system. Thirdly, the Chinese government adopted the laissez-faire approach of "development first and governance later" to regulate online car-hailing between 2010 and 2014. In July 2014, China's government issued a document to promote the coordinated development of various types of taxi telemarketing services and accelerate the sharing of information on the management of taxi services (Ministry of Transport of the People's Republic of China, 2014). Fourthly, passengers' mobility concept has changed. The mobility demand is no longer an asset requirement but a service requirement. The new generation of passengers is less willing to purchase cars, paying more attention to convenience and safety. There is some evidence of shift from seeing cars as status symbols and of people postponing car purchases and using alternatives (Cohen, 2019).

### 3.1.3. Niche level

The emergence of radical innovative technologies characterized the first phase of niche-level development. AVs are protected and nurtured in this phase; However, their social networks are fragile. Development paths are uncertain and through experimentation and trial-and-error learning. Since 1991, AVs entered China's Eighth Five-Year Plan (1991–1995) as a critical pre-research project for national defense, Chinese universities and companies have conducted a series of research. In 1992, the National University of Defence Technology (NUDT) developed the CITAVT- I, the first AV in China. In 2003, FAW Group and the NUDT jointly developed the Hongqi car with autonomous driving technology. The National Natural Science Foundation of China (NSFC) launched a "Cognitive Computing for Audio-visual Information" research program in 2009, which became a milestone in developing intelligent vehicles in China. Furthermore, the Chinese government has provided strategic protection space for innovative technologies to ease the pressure on the existing mobility regime temporarily. The Chinese government released "Made in China 2025" in 2015, identifying

**Table 3**
Robotaxi road test projects in China.

| Establishment date | Project | Participating companies | Location | Vehicle fleet size | Operating mileage |
|---|---|---|---|---|---|
| 2018.12 | Pony.ai robotaxi | Pony.ai | Guangzhou, China | More than 200 | More than 8 million km |
| 2019.8 | Didi robotaxi | Didi | Shanghai, China | More than 100 | More than 4 million km |
| 2019.9 | Apollo robotaxi | Baidu, FAW | Changsha, Cangzhou, China | More than 600 | More than 45 million kilometers |
| 2019.11 | Weride robotaxi | Weride, Baiyun Taxi Group | Guanngzhou, China | More than 300 | More than 11 million kilometers |
| 2020.4 | PacificaX | AutoX, FCA | Shenzhen, China | More than 1000 | More than 10 million kilometers |

Source：Authors' summary and compilation based on related information from Chinese government websites.

**Table 4**
Characteristics of transition and governance involving robotaxi service development.

| Phase | Transition w.r.t. the three levels | Governance | Regime actors |
|---|---|---|---|
| **Phase 1 (1991–2015)** | **1.Landscape level**<br>Accelerated urbanization<br>Energy security issues | A series of transportation demand management | Central government, local authorities |
| | **2.Regime level**<br>Car ownership growth bottleneck<br>The emergence of OCS<br>Prevalence of sharing economy | Access restrictions, quantity and price control for TTS<br>Laissez-faire approach of" development first, and governance later" to regulate OCS | Central government, local authorities |
| | **3.Niche level**<br>Incubate initial innovation | Set Labs, R&D centers to provide protection for innovation<br>Establish development legitimacy by releasing *"Made in China 2025"* | Central government, local authorities and enterprises |
| **Phase 2 (2016–2025)** | **1.Landscape level**<br>Urban agglomeration<br>economic growth driven to innovation-driven | Strengthen supply-side reform<br>Policies to support technological innovation | Central government, local authorities |
| | **2.Regime level**<br>Rapid increase in the market share of OCS<br>Considerable acceptance for shared mobility service | Clarify the legal status of OCS<br>Regulate the driver threshold, data security, user privacy, price setting and qualifications of the OCS<br>Supervise OCS' operating activities | Central government, local authorities |
| | **3.Niche level**<br>Set development goals<br>Define technical standards | Strategic planning settings in the medium and long term<br>Plans for infrastructure construction<br>Conducting AVs trials in closed areas | Central government, local authorities, and enterprises |
| **Phase 3 (2026–2035)** | **1.Landscape level**<br>Climate change mitigation<br>Automotive industry transformation | Action plan of carbon peaking by 2030<br>Releasing The New Energy Vehicle Industry Development Plan (2021–2035) | Central government |
| | **2.Regime level**<br>Institutional environment forming<br>Challenges in business models<br>Public preference improvement | Acceleration of the legislative process<br>Cooperation with different enterprises to achieve resource integration<br>Governance capacity improvement of transportation decision makers | Central government, enterprises |
| | **3.Niche level**<br>Infrastructure construction acceleration<br>Market share increase<br>Core technologies strengthen | Strengthen the construction of information infrastructure<br>Promote the agglomeration of industry and reduce costs | Local authorities, enterprises |
| **Phase 4 (2036–2050)** | **1.Landscape level**<br>Aging population<br>Carbon neutrality target | Announcement of carbon neutrality by 2060 | Central government |
| | **2.Regime level**<br>Technological substitution<br>Transition involving robotaxi service | Government-driven to market-driven<br>Guide public mobility awareness | Central government, local authorities, and enterprises |
| | **3.Niche level**<br>Positive effects<br>Adverse effects: VMT increase,urban sprawl | Encourage the use of robotaxi, strengthen the control of PAVs<br>Adopt government intervention to address negative effect | Central government, local authorities |

autonomous driving as one of the key directions for the future transition and upgrading of the automotive industry (State Council of the People's Republic of China, 2015), establishing legitimacy for developing and applying AVs.

### *3.2. Phase 2 (2016–2025): Innovation formation and stabilization*

#### *3.2.1. Landscape level*

China's industrialization and urbanization slowed down in the second transition stage. The demographic dividend is gradually fading, and the population problem shift from an aggregate excess to a structural supply shortage (Li, 2019). After 2015, the Chinese government held that the driving force of economic growth should be transformed from factor-driven to innovation-driven. At the same time, the contradiction between the increasing traffic demand and the limited urban space is becoming more and more severe. With a spurt of process in urban agglomerations, separating jobs and residences has increased mobility distances and higher demands on mobility services, making it a vital part of the public's quality of life. The annual growth rate of urban road space between 2010 and 2020 is 3.2%, while private car ownership has increased by 16.1%. Therefore, the increase in road infrastructure in China has not kept pace with the growth in the number of cars exacerbating the puzzle of traffic congestion. In 2019, four Chinese cities were in the top 10 of the Asian Cities Congestion Index, including Chongqing, Zhuhai, Guangzhou, and Beijing (TOMTOM, 2019). As a result, these issues gradually contribute to a gradual shift in urban mobility from a mere increase in the number of cars to an increase of use efficiency. These landscape pressures have led to the rapid growth and market share of shared mobility services, represented by online car-hailing. However, the COVID-19 poses an unprecedented challenge globally.

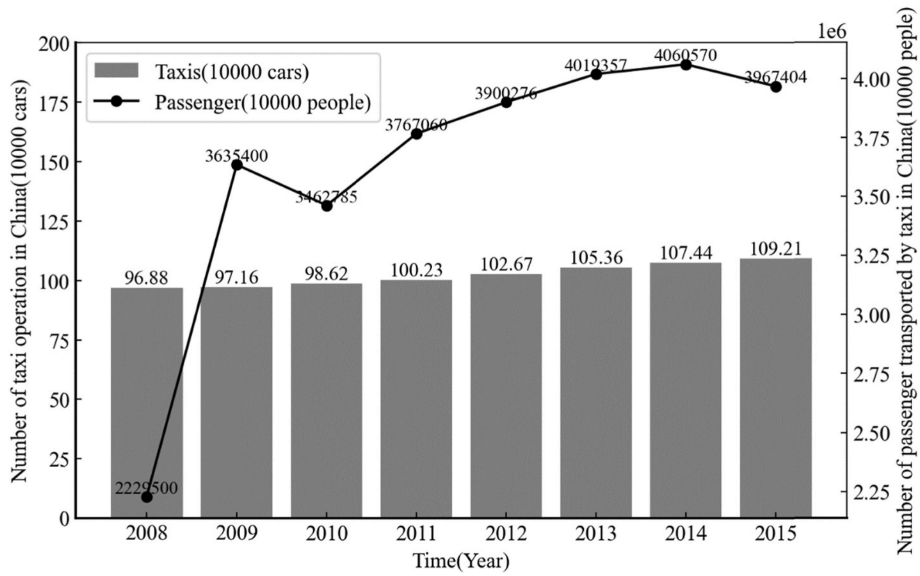


**Fig. 3.** Number of transition taxi and taxi passengers in China during 2008–2015.
Data source: National Bureau of Statistics of China, 2015.

The mobility industries have also affected heavily by the unexpected pandemic, especially for public transportation. Meantime, the COVID-19 has triggered new transport services based on autonomous driving and it is easy to see the enormous potential for robotaxi in the post-COVID-19 era. In the long term, the COVID-19 would accelerate the development of AVs (Grosbard, 2020), and push the transition for robotaxi service.

### 3.2.2. *Regime level*

Regarding service efficiency, an Australian study shows that the average wait time for Uber passengers was 4.5 min while waiting for a taxi took 8 min (Economics, 2016). Traffic safety is also a big plus-point of online car-hailing services (OCS), which has a 26% lower fatality rate than TTS for crashes over 100 million kilometers according to the Ministry of Emergency Management Information Research Institute (2019). However, OCS attracts a portion of public transportation traffic and may cause more severe congestion. OCS maybe account for extra 0.6 percent average annual growth in VMT (Choi et al., 2022) and cause an increase in the intensity (0.9% increase) and duration (4.5% increase) of road congestion (Shi et al., 2021). Unless ride-hailing applications substantially increase the average occupancy rate of trips and become shared or pooled ride-hailing, the impact is an increase in VKT (Tirachini & Gomez-Lobo, 2020). In this phase, a rapid increase in the market share of OCS can be seen. As shown in Fig. 4, the share of online car-hailing passenger traffic in total taxi passenger traffic in China increased from 16.6% to 31.9% from 2016 to 2021 (China National Information Centre, 2022). Whilst the TTS still dominates the taxi service regime, OCS changes the travel structure and modifies the trip mode split. Increasing instability within the system is accompanied by gradually increasing pressure at the landscape level, providing a window of opportunity for innovative niches.

Different actors involved in the socio-technical system in this phase

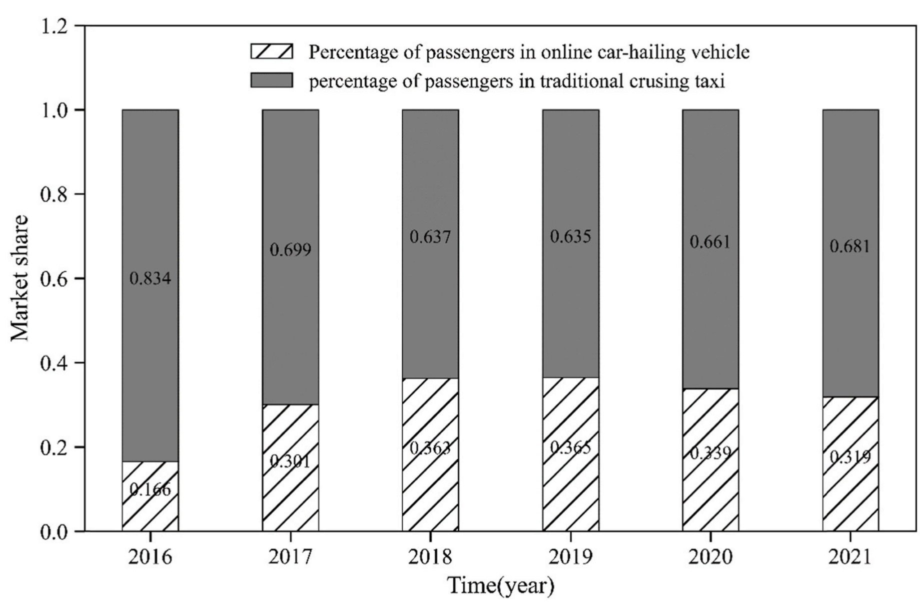


**Fig. 4.** Share of passenger traffic between online car-hailing vehicle and cruising taxis in China during 2016–2021.
Data source: China National Information Centre, 2022.

pave the way for the development of taxi services. At the end of 2021, there were already 258 online car-hailing companies in China, with 397 million users, accounting for 39.2% of China's overall internet users. The future expansion of the market size of OCS would mainly come from the increase in the frequency of use, hinging on the quality of mobility services. In addition, the rapid development of shared mobility, represented by OCS, is driving disruptive changes in the pattern of the automotive industry. The focus of traditional automakers is shifting from vehicle manufacturing to mobility services, and a new pattern would gradually take shape and provide a favorable market environment for robotaxi to enter the market.

Regarding policies and regulations, the Chinese government has coordinated the management of OCS and TTS during this period, reforming the existing taxi service regime and promoting the healthy development of the new industry of OCS. The Chinese government issued "Interim Measures for the Management of Internet-Reserved Taxi Operation and Services"(Ministry of Industry and Information Technology of the People's Republic of China, 2016) and "Guiding Opinions on Deepening the Reform and Promoting the Healthy Development of the Taxi Industry"(State Council of the People's Republic of China, 2016), which formally clarified the legal status of OCS. In 2018, the Chinese government issued policy documents to strictly regulate the driver threshold, data security, user privacy, and qualifications of the operating platform and strictly supervise OCS' operating activities. The policy to control the price-setting was issued in 2021 to grapple with the price discrimination behavior of OCS.

From the public acceptance perspective, Chinese passengers are more receptive to new technology-driven mobility services than those in Western countries. About 84% of Chinese participants considered giving up vehicle ownership for a robotaxi service, compared the ratios of 44% in the US and 46% in the UK (Alixpartners, 2020). On the other hand, taxi services, including OCS and TTS, have much lower travel costs than those in America, owing to lower labor costs in China (Chinese Society of Automotive Engineering, 2020). As a result, the public is more likely to abandon private cars and opt for shared mobility services in China. As shown in Fig. 5, according to China's first robotaxi passenger survey report, robotaxi is becoming an effective alternative to traditional taxis (Dai et al., 2021).

### 3.2.3. Niche level

In this phase, the technology niche requires experimentation to advance the adoption of technologies, and governance is needed to transition from the technology niche to the market niche. The social networks of the niche are small and unstable, and the rules of the niche are unstable and "in formation"(Geels, 2006). Governments, enterprises, universities, and industry consortia actively build niche networks in this phase.

Firstly, the Chinese government has developed a clear vision and strategy for developing AVs. After the Chinese government established the legal status of autonomous driving development through "Made in China 2025″ in 2015, it actively set medium and long-term development goals. In 2017 and 2020, it released "The Medium- and Long-Term Development Plan for the Automotive Industry" and "The Strategy for the Innovative Development of Intelligent Vehicles," which stabilized the legitimacy of AVs development and laid the foundation for the application of AVs. At the same time, the Chinese government has provided institutional protection for the technology niche and established technical standards that match the development of AVs in China. In conjunction with the current development of China's automotive industry, the Chinese government has released the "Taxonomy of Driving Automation for Vehicles" based on the SAE J3016 standard in 2020, which has become a prerequisite for the large-scale application of AVs to be implemented. At the same time, the government is active in the synergistic development of AVs and infrastructure. The government has vigorously implemented new infrastructures such as 5G networks and the Internet of Things. Knowledge support, such as research of core technologies, subsidies for major projects, and the introduction of talents and financial support, such as financial investment, subsidies, and financing, have been strengthened.

Local governments have also introduced AV-related policies, mainly focusing on opening public road test sections and establishing intelligently networked demonstration zones. Such policies have been making headway in parts of China. As shown in Table 3, internet companies are already conducting AVs trials in Beijing, Shanghai, Guangzhou, and Changsha in cooperation with car and taxi companies and Chinese AV technology companies. By the end of 2021, 38 provinces (cities) in China had issued management rules, established 70 test demonstration zones, opened more than 5200 km of test roads, and issued more than 1000 test licenses.

The niche actors have built a social network, providing a favorable environment for niche development. The China ITS Industry Alliance, led by the Ministry of Transport of China, includes technology

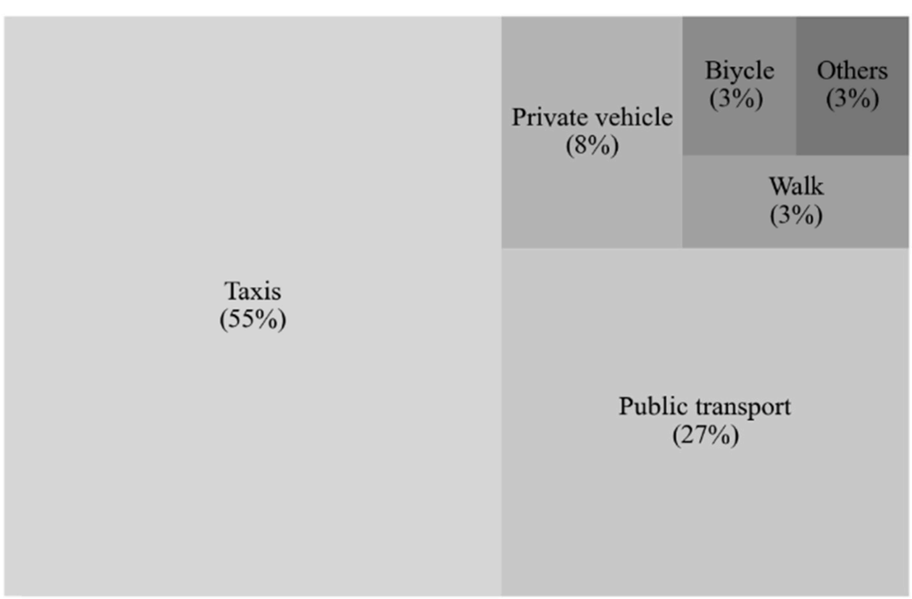


**Fig. 5.** Travel mode ratio that is most likely to be replaced by robotaxi.
Data source: WeRide Company & Tsinghua University, 2020-

enterprises, universities, and research institutes, was established. In January 2021, they drafted and released the robotaxi technical requirements group standard drafted by China ITS Industry Alliance was officially released, accelerating the commercialization of robotaxi.

### *3.3. Phase 3 (2026–2035):Widespread proliferation and breakthroughs*

#### *3.3.1. Landscape level*

Program of Building National Strength in Transportation, China's top-level transportation planning document, proposes that by 2035, China would basically become a country with a strong transportation network, and the transportation science and technology innovation system would be basically built (State Council of the People's Republic of China, 2019a). Meanwhile, the upgrade of China's automotive industry exerts a profound effect on the mobility system. It proposes that by 2035, high-level AVs (L4 and L5) would be used on a large scale (State Council of the People's Republic of China., 2020). New energy vehicles (NEVs) are more suitable for applying AVs than fuel vehicles. The combination with mobility services is more in line with the development trend of electrification, intelligence, network connectivity, and sharing. China's total carbon emissions are the highest in the world. In China, carbon emissions from transportation account for about 10% of total carbon emissions, with urban road transportation being the main source of carbon emissions (Institute of Internet Industry of Tsinghua University, 2022).

At the same time, to solve the problems of resources and carbon emissions, it is proposed that China's carbon emissions would peak at approximately 14 billion tonnes in 2030 and that CO2 emissions per tonne of GDP would drop by more than 65% compared to 2005 (State Council of the People's Republic of China, 2021a), requiring a more low-carbon and green mode of travel.

#### *3.3.2. Regime level*

This phase of the transition would see robotaxi enter the market.The Chinese government is moving forward with developing the innovation niche, setting out a vision for this phase by releasing a strategic plan. The proportion of total sales of PA (L2) and CA (L3) in China would exceed 50%, with high-level AVs (L4 and L5) first commercially available in specific scenarios and limited areas, and continuously expanding their operating range by 2025. By 2035, all types of advanced AVs would widely operate in a wide range of areas in China (National Smart Connected Vehicle Innovation Centre of China, 2020). In the preceding phases of the transition, technological development and closed scenarios applications are micro-niche innovations that cannot directly break through the lock-in of existing socio-technical systems. The Chinese government's strategy in this phase, which drives niche entry through policy interventions, creates a window of opportunity for the transition of taxi services. However, the taxi service system dominated by TTS is a coherent and highly interconnected structure of manually driven taxis, technology, user practices, standards, and regulations, with solid lock-in mechanisms and path dependencies. The transition would face obstacles in regulation, economy, and public attitude.

The existing regime's technical standards, laws, and regulations do not match the institutional environment required for robotaxi. The legislative process concerning AVs lags behind its development in China (Xue et al., 2020). The division of responsibility for traffic accidents involving AVs also poses a significant challenge to the existing legal system. However, the Chinese government issued "the Road Traffic Safety Law (Revised Draft)" in 2021, which clarifies the legality of road testing and road driving of AVs at the national legal level for the first time. Nevertheless, it lacks liability determination for actual scenarios and specific automation-level vehicles and is not very actionable. On-road and operational regulations and determining liability for accidents still need to be refined.

According to the expert interview shown in Section 2, "*The national government may concern the macrographic regulation of the AV-related industries. The regional government may concern the details of AV operation and management". Therefore,* the central government would be responsible for formulating policies and regulations and regulatory measures in the future, such as access mechanisms, traffic regulations, insurance regulations, and vehicle quality control. Local governments would likely perform regulatory duties, such as transportation infrastructure standards, AV license issuance, charging station planning, vehicle price control, and insurance claims.

Regarding economic barriers, first, the existing taxi service system's production technology, machinery, and equipment are compatible with manually driven taxis rather than robotaxi. These sunk costs give automakers, taxi operating companies, and traditional mobility service providers less incentive to develop robotaxi on a large scale. Second, the established market access mechanism, pricing mechanism, and passengers' mobility habits inhibit the commercialization of robotaxi. Due to the immaturity of the technology and the lack of economies of scale, the initial cost of robotaxi was high, leading to poor market competitiveness. Third, AVs would likely force a paradigm shift within the automotive industry, where a significant share of private automobiles would be replaced by mobility services (Skeete, 2018). Robotaxi has led to a shift in vehicle ownership from individuals to some commercial fleet providers, which has also changed the business model of regime actors (Pütz et al., 2019).

The large scale of robotaxi requires companies to develop a strong focus on technology (advanced AV-related technology), platforms (massive mobility data), and services (customized mobility services). In response to these obstacles, companies might invest a lot of talent and technical capital to achieve transition and make the necessary changes in culture, organizational structure, and management modes. The traditional automotive ecosystem faces the most prominent changes and needs to make strategic choices about the business model to accommodate the long investment period required for this technological leap (Alixpartners, 2020). In particular, traditional automakers and taxi operators need to strengthen cooperation with internet and technology companies to achieve complementary advantages and resource integration.

To some extent, the public's preference for existing services has discouraged the large-scale commercialization of robotaxi. Firstly, the car is not just a tool for traveling. It has become a status symbol representing power, success, and audacity (Geels, 2012). Despite some evidence that this is changing (Cohen, 2019), it may still be challenging to prompt the public to reduce or abandon car ownership. Therefore, society's cultural attachment to the personal freedom of the private car is a significant source of inertia in the transition (Wells & Xenias, 2015). Moreover, individual safety incidents due to immature technology can easily create adverse public opinion, leading to resistance and fear among the public who are unfamiliar with AV technology. To improve public acceptance, it would be necessary to increase public awareness and knowledge of AV. Mobility service providers encourage passengers to experience robotaxi service, for example, through public and private sector fleets and taxi fleets, promoting robotaxi test drive activities and car-sharing clubs, influencing behavior change. Therefore, more job opportunities for AV are needed, such as algorithm engineers, data trainers, and robotaxi experience designers.

#### *3.3.3. Niche level*

The transition faces not only obstacles at the regime level but also constraints at the niche level in terms of core technology, infrastructure, and cost, which cannot meet the requirement of mass-market. Advanced AVs would face barriers to safety, operational design domain (ODD) limitations, and economics. At this phase, driving forces are not only technological innovations but also business strategies and infrastructure construction. Firstly, AV-related companies, universities, and research units should continue strengthening research to break through technical bottlenecks. Secondly, The Chinese government should accelerate the formation of AV industry clusters to grind down costs, stimulate technological innovation, and form a virtuous cycle. Thirdly, vehicle-infrastructure cooperated autonomous driving (VICDA) is an inevitable trend for commercialization at scale (Institute of AI Industry Research of Tsinghua University, 2021). The transition towards robotaxi requires not only breakthroughs in the core technologies of intelligent vehicles (e.g., sensing technology, decision control technology) but also the construction of intelligent roads (e.g., intelligent sensing facilities, roadside communication facilities, highly automated driving maps). At the same time, there would need to be promotion of the construction of information infrastructure based on the evolution of the new generation of information technology generated by 5G base stations, AI, big data centers, and the industrial internet.

### 3.4. Phase 4 (2036–2050): Stabilization and institutionalization

#### 3.4.1. Landscape level

This period would be expected to see the continuation of landscape development from the previous period. According to UN data, China's urban population is predicted to increase by 255 million in 2050, with an urbanization rate of 80.03% (United Nations, 2019).In 2050, China's elderly population over 65 would reach 380 million, accounting for 27.9% of the total population (China Development Research Foundation, 2020). In the face of this, China's government advances transport sector reforms by strengthening the capacity for scientific and technological innovation in dealing with the aging population(State Council of the People's Republic of China, 2019b), making mobility services accessible to the elder. With the development of energy technology, the cost of new energy would be rapidly reduced. The accelerated transition to clean and low-carbon energy has become a global trend. The Chinese government has announced a plan to achieve carbon neutrality by 2060 (State Council of the People's Republic of China, 2021b). As an essential way to achieve this goal, AVs would need to enter the phase of electrification driven by both market and policy. The mobility industry needs to build an innovation system for low-carbon development, striving to achieve the goal of carbon neutrality in urban travel as planned.

#### 3.4.2. Regime level

It may be 2030s before Robotaxi would be widely available (Kaltenhäuser et al., 2020). The time delay between the introduction of AVs and robotaxi is the most critical parameter for the successful large-scale introduction of autonomous vehicles (Litman, 2022). It is estimated that 53% of AVs cars (7–39% of the global car fleet) would be applied in the shared scenario in 2040 (World Economic Forum, 2015), which indicates that robotaxi would gradually take a larger market share in the taxi and auto-mobility industries. As the robotaxi market share increases, the technological substitution of taxi service would occur. Infrastructure, policies, industrial structures, regulations, and standards would be dramatically adjusted, and a robotaxi based taxi regime would be formed and gradually stabilized and institutionalized. At this phase, the government's role in protecting innovation niches would expect to slowly diminish, and the role of the market gradually come to the fore, promoting competition between niches within the system and stimulating independent innovation capabilities. Moreover, robotaxi technological innovation can be seen as a progressive development within the system.

#### 3.4.3. Niche level

Combining the advantages of online car-hailing and autonomous driving technology, the large-scale application of robotaxi could bring many positive effects to the mobility service. Firstly, robotaxi could contribute to traffic safety. CIDAS has found that the human factor in driving is about 81.5% (China Automotive Technology and Research Center et al., 2021), and robotaxi would reduce human errors in driving through AV technology, reducing the loss of life and property due to traffic accidents. Secondly, the robotaxi service could make more efficient use of land resources. A robotaxi can replace 2.8–3.7 carsharing vehicles (Dandl & Bogenberger, 2018), significantly reducing traffic density and alleviating traffic congestion. Thirdly, the mass adoption could provide a more inclusive mobility service, making it more convenient and accessible for people with limited mobility (e.g., elderly, disabled) (Francis, 2017). Fourthly, robotaxi services could also significantly accelerate the penetration of electric vehicles, bringing environmental and economic benefits (Jones & Leibowicz, 2019). A fleet of electrically powered robotaxi would reduce greenhouse gas emissions by 73% and energy consumption by 58% compared to a fleet of fuel-powered taxis (Bansal & Kockelman, 2018). Fifthly, robotaxi services are more economical than traditional taxi services (Levin, 2017; Wadud, 2017). It can reduce its operating costs by 29–35% with the exact cost structure of taxi services (Iacobucci et al., 2018). Meanwhile, the large-scale commercialization of AVs would also bring adverse effects. It potentially leads to an increase in vehicle miles travelled (VMT) and deadheading miles due to cruise parking, which could lead to a 13% increase in total miles travelled (Wadud et al., 2016; Zhang et al., 2018). Moreover, it is predicted that VMT and sprawl could increase by 10–30% in the 2040s (Litman, 2022).

According to the expert interview, "After long-term development, when the proportion of self-driving cars approaches or exceeds that of traditional cars, the existing traffic problems would be fundamentally managed." Experts predicted that when robotaxi occupied most of the market share, due to intelligent regulation, the volume of traffic trips would gradually decrease, traffic congestion would gradually ease, and traffic accidents would be significantly reduced. Besides, the lower commuting costs due to AVs may contribute to urban sprawl if appropriate management measures are not taken. To alleviate urban sprawl, transportation managers should encourage the use of robotaxi, strengthen the control of PAVs (private autonomous vehicles), and accelerate the robotaxi marketization process. In particular, the rapid introduction of robotaxi can reduce VMT (Kaltenhäuser et al., 2020). According to the expert interview, "*The shared autonomous vehicles would help promote carsharing and ridesharing, and provide on-demand mobility service, which can be helpful to increase the traffic efficiency and improve future urban transportation*". Therefore, AV without sharing might increase traffic congestion. Under the mass adoption of AVs, adopting a package of government intervention could be expected to lead to better performance against the generic traffic flow and accessibility objectives than a laissez-faire approach (Cohen & Cavoli, 2019). Authorities need to operate a combination of transportation demand management approaches, such as introducing congestion charging, rationalizing parking zones, encouraging carpooling, banning deadheading AVs, and optimizing interchange between robotaxi and high-occupancy vehicles. From an economic and transport system point of view, using SAV fleets (robotaxi fleets)instead of buses and integrating regional railways, compared to replacing existing public transport with AVs, Is a more attractive solution(Imhof et al., 2020).

### 3.5. Summary

As shown in the following Table 4, the critical characteristics of transition and governance involving the robotaxi service development are further summarized with respect to the four phases.

## 4. Discussion

According to the robotaxi service transition process investigation in China, it is worth to note that the transition is not just about the mass marketization of robotaxi, but also about providing services driven by mobility demand. Robotaxi service would disrupt the private ownership business model and promote the development of the mobility as a service (MaaS) business model.

The transition of taxi service is not just technology-driven changes in travel modes but also reflects a shift from a cruising service dominated by traditional cruising taxis to an on-demand service dominated by online car-hailing taxis and robotaxi. This process has also propelled regime actors to explore the MaaS business model. MaaS business model provides new entrances and incumbents in the system to accommodate the radical transition. In the second transition phase of Section 3.2, many automakers have actually transformed into mobility service providers and/or partnered with new entrances i.e., AV technology companies and telecommunication companies. MaaS integrates various forms of transport services into a single mobility service which is accessible on demand (Maas Alliance, 2017). As travel services become more accessible to the public, car ownership becomes less necessary. The value of TTS and OCS is mainly in vehicle ownership and operation, but robotaxi services would require regime actors to move from “providing transport services” to “providing mobility solutions.” As shown in Fig. 6, robotaxi service would provide new products, solutions, and services and explore new business models. In the future, actors in the robotaxi service system might adopt MaaS business model, which make full use of autonomous driving, data sharing and cooperative vehicle infrastructure technologies to provide passengers with seamless mobility services.

MaaS seeks to transform individual transportation systems from (mostly) fragmented to (more) polycentric to obtain public benefits by changing the modal split in the mobility system (Smith & Hensher, 2020). Passengers might use the MaaS platform to customize their trips, operators would provide intelligent routes and scheduling algorithms, and mobility service providers would provide more seamless and convenient mobility services. It enables the travel data sharing to support multiple modes of intermodal transport, including car sharing, car rental, bicycle sharing, shared parking, metro, bus, and taxi (Wang et al., 2021). The one-stop, full-process mobility service might reduce the use and purchase of private cars, guide passengers to choose public transportation more often (Long et al., 2019). Real-time data feedback and dynamic pricing might guide people to travel off-peak hours, gradually changing their travel habits. For transportation managers, MaaS would also increases the resilience of urban transport by enabling a shift in transport management towards integrating all modes of transportation. They would provide a timely and dynamic response to public safety risks by leveraging 5G technology and the Internet of Things.

Currently, MaaS is being explored in several cities worldwide, such as Whim in Finland, UbiGo in Sweden, and MinRejseplan in Copenhagen. In China, the Beijing Municipal Commission of Transportation and A map company have jointly launched an integrated service platform for encouraging green mobility. Baidu Apollo’s MaaS-based autonomous driving service system has been piloted in China. It can integrate robotaxi, minibus, and other modes on a unified service platform. Moreover, China is also actively promoting the development of multimodal innovative bus services, with a gradual emphasis on integrated and personalized services for multiple modes of public transportation (Xu et al., 2022). It is estimated that transport trips worldwide might double by 2050 (Arthur D Little, 2019), which requires urban mobility service systems to have more comprehensive and coordinated supply management and move towards more proactive mobility demand management. Taxi services, as a complement to public mobility services, could also consider the synergistic development to achieve the sustainability of the mobility ecosystem.

## 5. Conclusions

With the MLP approach, this study investigates robotaxi service transition and governance in China. The interaction of the three MLP layers i.e. landscape, regime, niche, is identified for the robotaxi service transition in China. Since 1991, China has experienced a massive population shift from rural to urban areas and a shift in the economic development growth from the resource elements aggregation and input driven to innovation driven. The exogenous environment of China, such as climate change, energy shortage, demographic structure, and economic development, nurtures the space for autonomous driving development and inhibits the potential development of traditional taxi services. China’s urban space and mobility supply are shifting towards stock optimization, and mobility service has pivoted with passengers’ travel demands. Internet technology has driven the creation and market entry of online car-hailing services. As the car-hailing market share increased, it changed the landscape of the mobility industry to some extent while influencing public mobility perceptions and creating a positive environment for the introduction of niche innovation. Robotaxi, a niche product seeking to disrupt the existing regime, faces obstacles in regulation, economy, and consumer awareness caused by the lock-in mechanism of the existing system. To achieve the transition of taxi service, regime actors, including local government, related enterprises, transport authorities, and the public, would all need to act to develop an environment suitable for robotaxi service development.

Through the investigation, we conclude that the transition of taxi services driven by autonomous driving technology could last for years. This transition follows the reconfiguration pathway, caused by

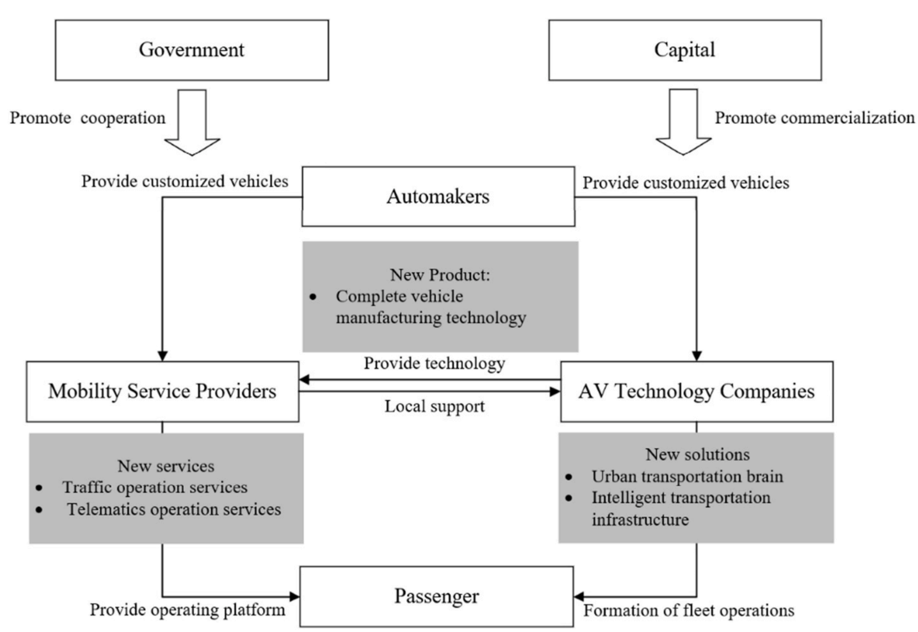


**Fig. 6.** Actors’ interaction within robotaxi service system.

sequences of multiple component innovations. Online car-hailing is an innovation of internet technology-driven development based on traditional cruising taxis, and robotaxi is an innovation of autonomous driving technology-driven development based on online car-hailing service system. In the first phase, governance focuses on defining the legal status of AVs and developing strategic plans to shield and nurture the development of robotaxi. In the second phase, regime actors need to regulate the technical norms, legal liability, and operational standards and provide specific road test scenarios for robotaxi. In the third phase, practitioners need to strengthen infrastructure construction and grind down operating costs whilst improve the competitiveness of robotaxi service to entering the market. In the fourth phase, the government could guide public travel concepts and implement related travel demand management policies to promote the successful transition of robotaxi-dominated taxi services. Meanwhile, transport authorities could take the initiative to guide demand and meet the demand for integrated mobility services by constructing, organizing, and regulating robotaxi service. Robotaxi services themselves might promote the development of the MaaS business model.

There are several limitations to this paper that future research could address. Firstly, the interactions of the robotaxi service with other mobility services, such as auto-mobility, bus, and subway, during the transition process, should be studied. Secondly, the transition impacts can be further studied concerning sustainability development under its three pillars, i.e., economic, social, and environmental. Some key factors, e.g., carbon emissions, accessibility, and parking space, can be included. And moreover, the transition process of the mobility system at different scales, e.g., cities/urban agglomerations/countries/regions, can be focused on and compared.

## CRediT authorship contribution statement

**Yimin Zhou:** Conceptualization, Methodology, Data curation, Visualization, Investigation, Writing – original draft. **Meng Xu:** Conceptualization, Methodology, Expert interview, Data curation, Formal analysis, Writing – review & editing, critically for important intellectual content, approval of the version of the manuscript to be published.

## Declaration of competing interest

The authors declare that we have no conflict of interest in the submission of this work for consideration by the journal Research in Transportation Economics.

## Data availability

No data was used for the research described in the article.

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