The Innovation Effect of Intelligent Connected Vehicle Policies in China

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ABSTRACT “Intelligence” and “networking” have become the inevitable trends in the global automobile industry; the intelligent connected vehicle industry has developed rapidly. Existing studies on innovative technology policies of the automobile industry mainly focus on new energy vehicles and seldom analyze or evaluate the industrial policies of intelligent connected vehicles. In this paper, we compared the intelligent connected vehicle policies of the U.S., the EU, Japan and China and sorted out, classified and explored the local industrial policies of intelligent connected vehicles issued by major cities in China since 2016. We then evaluate the innovation performance of local industrial policies for intelligent connected vehicles using the multiperiod difference-in-differences (DID) method. The results show that local intelligent connected vehicle policies in cities such as Beijing, Shanghai and Guangzhou can significantly promote industrial innovation. Moreover, these cities choose more environment-oriented industrial policies represented by target planning and legal regulation, making the industrial layout more comprehensive and industrial development more systematic. We further provide a reference and policy suggestions for other cities to formulate local industrial policies in the initial stage of the intelligent connected vehicle industry.

INDEX TERMS Industrial Innovation, Intelligent Connected Vehicles, Local Industrial Policy, Multiperiod Difference-in-Differences (DID) Method, Policy Evaluation

I. INTRODUCTION

In recent years, China's transportation science and technology innovation system has been constantly improved. Major scientific and technological achievements have provided strong support for the leapfrog development of transportation. However, the transport science and technology innovation system needs to be improved, the science and technology innovation chain needs to be optimized, and the lack of high-level science and technology innovation platforms is still a significant obstacle to building transport power. On August 25, 2021, the Ministry of Transport and the Ministry of Science and Technology jointly issued the “Opinions on Accelerating the Construction of Transportation Power Driven by Scientific and Technological Innovation”, calling for strengthening key technologies, promoting industrial innovation and improving technological innovation capacity. We seek to improve the mechanism for scientific and technological innovation, accelerate the building of a scientific and technological innovation system that meets the needs of a transport country, and give full play to the key role of scientific and technological innovation in accelerating the building of a transport country.

A transport power is, first of all, a transport science and technology power, and scientific and technological innovation is bound to be the principal driving force for the construction of a transport power. The development and...
application of intelligent connected vehicle technology is an important part of accelerating China's development into a transportation power supported by scientific and technological innovation. Intelligent connected vehicles (hereafter referred to as ICVs) are new-generation vehicles equipped with advanced sensors and new technologies such as artificial intelligence. With an automatic driving function, ICVs have gradually become the new generation of intelligent mobile space and application terminals. ICVs use a comprehensive system that integrates environmental perception, planning and decision-making, multilevel assisted driving and other functions by using computer, modern sensing, information fusion, communication, artificial intelligence and automatic control technologies. It is a typical high-tech complex. The ICV industry is the product of the integrated development of the new generation of information technology and transportation, which produces positive economic and social benefits. It is expected to become the leading factor in reshaping the road transportation system and an important direction for the upgrading of the automobile industry chain and the cultivation and expansion of new functions of economic growth.

The State Council, the Ministry of Industry and Information Technology, the Ministry of Transport and other departments issued a series of policy opinions to guide and regulate the development of the ICV industry. For example, in 2015, “Made in China 2025”, officially promulgated by the State Council, regarded driverless vehicles as one of the important directions for the future transformation and upgrading of the automobile industry [1]. In 2020, the National Development and Reform Commission and 11 ministries and commissions jointly issued the “Innovation and Development Strategy of Intelligent Connected Vehicles”, which solidified the goal of making China an ICV leader [2]. At the same time, local governments, such as Hangzhou, Beijing, Shanghai, and Wuhan, have also responded to the national call for transport transformation, complying with the industrial development trend and the successively issued relevant policies. Developing the ICV industry has been a strategic policy. These policies focus on connected and intelligent development and plan to gradually shift from single-vehicle intelligence to multivehicle collaboration, as well as the collaborative development of “smart cars” and “smart roads”, putting forward innovative development demands for technological innovation and product research and development. On the whole, the government attaches great importance to the development of the industry and has created a policy environment conducive to the growth of the domestic ICV industry.

However, ICVs involve a wide range of fields, involving more government departments. How to coordinate the interconnected and integrated development of multiple industries and improve the speed and quality of industrial development faces many challenges. To promote the development of the ICV industry, it is necessary to use policy instruments rationally. Government innovation policy intends to influence or change technological innovation's speed, direction and scale. Its main purpose is to shorten the time from invention to commercial application, speed up the transformation of science, and realize technological achievements from potential to actual productivity. The government engages in policy-making through the design, organization, collocation and application of various policy instruments, which are the means to achieve the goal of innovative policy. The rational selection of policy instruments is the basic guarantee for the smooth realization of policy objectives. Traditionally, policy-makers tended to adopt fixed, off-the-shelf policy instruments to solve problems. However, with the change of time and environment, policy-makers should conduct more analysis to fully consider the characteristics of the industry and select the policy instruments that are most effective at promoting industry development. In the early stage of the ICV industry, how should local governments reasonably choose policy instruments? No relevant research has been conducted on this topic.

In this paper, we attempt to explore the characteristics and mechanisms of ICV industry policies in some first-tier cities in China; we use a causal identification method to quantitatively evaluate the innovation performance of local ICV policies and analyze the implementation effect and impact of policies on local ICV industry innovation. The potential contributions of this paper to the existing literature are as follows: first, we systematically sort out the industrial policies of ICV in some prefecture-level cities in China and classify and analyze the policies; second, we use a multiperiod DID model, which can fit the occurrence time of different policies compared to the classical DID method, to evaluate the innovation performance of ICV industry policy in some cities in China; and third, according to the research conclusions, we propose policy suggestions for other cities to formulate local industrial policies in the initial stage of the ICV industry.

Section 2 reviews the relevant literature. Section 3 analyzes the ICV policies. Section 4 describes the model design. Section 5 presents and analyzes the empirical results. Section 6 carries out a parallel trend test and a dynamic effect analysis. Section 7 performs a robustness test. Section 8 provides the conclusion and insights.

II. LITERATURE REVIEW

At present, relevant studies on the ICV industry mainly adopt two perspectives: technology and industrial policy. In terms of technology, some international researchers have focused on improving car safety through artificial intelligence application technology and other high-tech approaches [3]-[5] and some Chinese researchers have paid attention to patent technology. For example, Jiang et al. [6] studied the technology development trend of ICVs based on...
global ICV patent technology. Some authors have performed a systematic basic analysis of ICV industrial policies and regulations to provide future suggestions for development [7]-[9]. Kuang et al. [10] assessed the socioeconomic impacts of ICV in China by using a cost–benefit analysis. In addition, some scholars have focused their study interests on policy performance evaluation in the new energy vehicle industry. Chen et al. [11] studied the performance of policies on the national and local new energy vehicle industry, finding that the industry was still backward and that awareness of intellectual property protection was also weak. Lu et al. [12] carried out a comparative analysis of the new energy vehicle industry policy of the BRICS countries by using the content analysis method, constructing a theoretical system and identifying existing problems. Zhou et al. [13] found that Chinese firms may strategize their upgrading pathways toward intelligent manufacturing according to their capabilities and industrial specifics; furthermore, this finding can be extended to other catching-up economies. Their paper provided a strategic roadmap to manufacturing firms, policy-makers, and investors. However, few scholars have researched policy performance evaluation in ICVs.

The existing studies on policy instruments mainly focus on instrument classification and their operational mechanisms. In 1965, the Dutch economist Kurabayashi [14] first classified policy instruments into 64 categories, but he just roughly listed relevant economic policies without systematic generalization. Based on this, McDonell and Elmore [15] divided policy instruments into four categories according to the policy objectives: command, persuasive, capacity building, and institutional change. Schneider [16] classified policy instruments into four categories: learning, motivation, advice and ability improvement. According to different research fields, Rothwell [17] focused on industrial revival and technology research, proposing that policy instruments be divided into supply-type, environmental-type and demand-type. Currently, this classification method has become the most widely used and practical method because of its strong goal relevance and content guidance. Among the three types, supply-type and demand-type policy instruments mainly have a direct impact on the technology application market, while environmental-type instruments often play an indirect role in industrial development [18]. In the field of public policy, research on environmental policy instruments is more systematic. For example, Xu et al. [19] systematically summarized the three aspects of environmental policy instruments in China: enterprise production, technology updates and the cost efficiency of instrument application. Xu et al. [20] found that government intervention has a significant moderating effect on technology diffusion in a manufacturing paradigm shift by a service platform oriented to general technology. However, there is still little research on how to choose policy instruments for different industries.

For the measures used to evaluate policies, many scholars have proven that industrial policies can actually promote industrial development [21]. Generally, metrology-related methods are widely used in policy performance evaluation, especially the difference-in-differences method (DID) [22]. In 1978, Ashenfelter [23] applied the DID method to the economy. The other four methods above are all based on this method. In 1985, Heckman et al. [24] used DID in policy performance evaluation and developed the propensity score matching DID method (PSM-DID) to evaluate the effectiveness of job training programs in 1997. Zhou et al. [25] assessed the impacts of municipal-level environmental policy mixes on the textile industry in 13 Chinese cities by using the difference-in-differences technique to analyze the microfirm panel data of 12,133 Chinese textile firms from 1998 to 2012. To solve the DID requirement that the control group must be consistent with the time change trend of the processing group, a difference-in-difference-in-differences method (DDD) was designed. Tong and Gong [26] used this method to learn the effect of the population control policy in Beijing since 2015. At the same time, the synthetic control method (SCM) is a nonparametric method stemming from DID, which Abadie and Gardeazabal [27] first proposed in 2003 to assess the economic impact of terrorism conflict. Similar to the DDD method used to solve the DID limit, the regression control method (RCM) has been extensively applied by scholars [28], [29]. These methods all share the general idea of setting processing and control groups to calculate the effects of policy implementation before and after [30]. However, few researchers have applied these methods to the ICV industry.

From the above analysis, more research focuses on innovative technology policies for the new energy vehicles industry, but few studies focus on the ICV industry. Moreover, there are even fewer studies that conduct quantitative analysis and evaluation of the policies. Because the effect of industrial policy is uncertain and different types of policies have different effects [31], it is necessary to combine and evaluate ICV industrial policies. In this paper, we attempt to explore the characteristics and mechanisms of local ICV industrial policies in China and quantitatively evaluate the innovation performance of local ICV policies in some cities by using the causal identification method. Finally, we explore the implementation effect of these ICV policies and their impact on innovation.

III. POLICY ANALYSIS OF INTELLIGENT CONNECTED VEHICLES

A. NATIONAL INTELLIGENT CONNECTED VEHICLE POLICY

At present, the United States, the European Union, Japan, China and other major countries and global regions have adopted ICV as an important future direction for the development of the automobile industry. They have accelerated the industrial layout, formulated development
strategies, and successively launched various policies and plans to promote the development of their own ICV industry. See Table I for the relevant strategic plans and policies of each country.

**TABLE I**

**THE RELEASE YEAR AND CONTENT OF THE INTELLIGENT CONNECTED VEHICLE POLICY IN SOME COUNTRIES**

| Country | Year of publication | Main content |
|---------|---------------------|--------------|
| Japan   | 2013                | "Preliminary Statement of Policy Concerning Automated Vehicles" It supports the development and dissemination of autonomous driving technology but does not recommend that states legislate to allow autonomous vehicles on the road beyond their testing purposes. |
|         |                     | "US DOT’s Intelligent Transportation Systems (ITS) Strategic Plan 2015-2019" It makes clear that the American ITS strategy is upgraded to the dual development strategy of interconnection and intelligentization. "Federal Automated Vehicles Policy" It brings the safety regulation of autonomous driving into a federal legal framework for the first time. |
|         | 2015                | "Automated Driving Systems 2.0: A Vision for Safety" It encourages states to reevaluate existing traffic laws and regulations to remove legal barriers to the testing and deployment of self-driving technology. "Preparing for the Future of Transportation: Automated Vehicles 3.0" It continues to promote the safe integration of autonomous driving technology with multiple modes of transportation in ground transportation systems. "Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0" It proposes that the U.S. takes the lead in autonomous driving and establishes ten principles. "The ITS Directive" It is the first legal basis document for harmonizing the deployment of ITS within the European Union. "Horizon 2020" It promotes the development of intelligent connected vehicles. "GEAR 2030" It focuses on promoting and cooperating in areas such as highly automated and connected driving. |
|         | 2016                | "European Strategy on Cooperative Intelligent Transport Systems (C-ITS)" It aims at promoting the deployment of Collaborative Intelligent Transport System (C-ITS) services, such as V2V, V2I and other networked information services, across EU member states by 2019. "Road to automated mobility: An EU strategy for mobility of the future" It aims to achieve autonomous driving on highways by 2020 and a fully autonomous society by 2030. "A manifesto to create the world’s leading IT nation" It has designated intelligent connected vehicles as one of its core industries. |
|         | 2017                | "Strategic Innovation and Creation Program (SIP)" It elevates the research and development of autonomous driving systems to the height of national strategy. "ITS 2014-2030 Technology Development Roadmap" It plans to build the world’s safest roads by 2020 and the world’s safest and most accessible roads by 2030. "Innovation of Automated Driving for Universal Services(SIP-adus)" It promotes the development and implementation of basic technologies and related areas of collaborative systems. "Government and Civil ITS concept and roadmap in 2017" It sets a timeline for autonomous propulsion. "Outline of autonomous driving-related system preparation" It clarifies the responsibilities of autonomous vehicles. "A guide to safety technology for autonomous vehicles" It specifies the safety conditions that self-driving cars need to meet. "Made in China 2025" It sets unmanned driving as one of the important directions for the future transformation and upgrading of the automobile industry. "Promote "Internet +" convenient transportation to promote the development of intelligent transportation implementation plan" It proposes the overall framework and implementation measures for China's intelligent transportation. "Medium- and long-term development plan of automobile industry" It proposes to take intelligent connected vehicles as one of the breakthroughs to lead the transformation and upgrading of the entire industry. "Intelligent Vehicle Innovation and Development Strategy (Draft)" It is clear that by 2020, the proportion of new smart vehicles will reach 50%, the market application of medium- and high-level smart vehicles will be realized, and the demonstration operation in key areas will achieve results. "Code for Road Test management of Intelligent Connected Vehicles (Trial)" It requires local governments to formulate implementation rules and organize road tests for autonomous driving. "Internet of Vehicles (Intelligent Connected Vehicles) Industry Development Action Plan" It clearly takes 2020 as the timeframe to achieve high-quality development of the internet of vehicles industry in two stages. "Intelligent Vehicle Innovation and Development Strategy" It is clear that by 2025, intelligent vehicles with conditional autonomous driving will be produced on a large scale, and by 2035–2050, China's standard intelligent vehicle system will be fully completed and improved. |
|         | 2018                |                                                                 |

Data source: Author-collated based on the report of Ruiguan Consulting and related data.
It can be seen that in this round of scientific and technological revolution and industrial transformation, the United States, the European Union, Japan and other developed countries took the lead and developed the ICV industry. Although China started late in the ICV development race, it has launched a number of policies since 2015 to advance its development, which is gradually maturing and is expected to realize large-scale commercial use.

B. INTELLIGENT CONNECTED VEHICLE POLICIES IN MAJOR CITIES IN CHINA

Since 2016, in response to the national call, Beijing, Shanghai, Guangzhou and other cities have issued local ICV policies to improve the development environment and provide support for the progress and application of ICV technology. In this paper, we take the first local ICV industry policy as the policy implementation year and sort out the first ICV policy's release year and main contents in some cities (see Table II for details).

| City       | Year of publication | Main content                                                                 |
|------------|---------------------|-----------------------------------------------------------------------------|
| Beijing    | 2016                | “Beijing Intelligent Connected Driving Technology Innovation Project (2016–2025)” Put forward the research and development, demonstration application and industrial development goals of Beijing intelligent connected driving technology. |
| Shanghai   | 2016                | “Outline of the 13th Five-Year Plan for National Economic and Social Development in Shanghai” It is proposed that the automobile industry should be upgraded to intelligent connected vehicles and new energy vehicles. |
| Nanjing    | 2016                | Layout the intelligent connected vehicle industry cluster in the Lishui Economic Development Zone and open the intelligent connected vehicle road test. |
| Wuhan      | 2016                | Wuhan has become one of the first and the only demonstration cities in China for the application of intelligent connected vehicles and intelligent transportation |
| Hefei      | 2016                | The national intelligent connected electric vehicle quality inspection center settled. |
| Guangzhou  | 2017                | The Ministry of Industry and Information Technology and the Guangdong Provincial Government jointly support Guangzhou in the promotion of the industrialization of intelligent connected vehicles and the creation of demonstration zones for smart cars and smart transportation based on broadband mobile internet. |
| Changchun  | 2018                | “Administrative Measures for Road Test of Intelligent Connected Vehicles in Changchun (Trial)” |
| Tianjin    | 2018                | “Administrative Measures for Road Test of Intelligent Connected Vehicles in Tianjin (Trial)” |
| Changsha   | 2018                | “Implementation Rules of Changsha Intelligent Connected Vehicles Road Test Management (Trial)” |
| Shenzhen   | 2018                | “Implementation Opinions of Shenzhen on ‘Implementing the Management Standard of Intelligent Connected Vehicles Road Test (Trial)’” |
| Jinan      | 2018                | “Administrative Measures for Road Test of Intelligent Connected Vehicles in Jinan (Trial)” |
| Chengdu    | 2019                | “Implementation Plan for The Development of Intelligent Connected Vehicles Industry in Chengdu (2019–2021)” |
| Ningbo     | 2019                | Ningbo Hangzhou Bay Smart City National Demonstration Project Signed |
| Suzhou     | 2019                | Construction of provincial internet of Vehicles pilot area |

Data source: Author-collated relevant data.

C. POLICY TYPE AND POLICY INSTRUMENT

To clarify the types of local ICV policies and better analyze their impacts, we introduce a classic industrial policy classification method, namely, Hanson's [32] industrial policy classification standard. They introduced policy instruments into innovation policy analysis earlier and divided them into supply-oriented, environment-oriented and demand-oriented policies according to the different levels of impact on technological innovation (see Figure 1 for details). This classification reduces the dimension of the complex innovation policy system from the perspective of instruments and measures. It has significant intradimension aggregation validity and interdimension differentiation validity and strong target pertinence and content guidance; thus, it is widely used in policy research.

Supply-oriented policy instruments refer to the government's input in human, material, financial and information technology, which directly expands the
government's supply of various elements of innovation and lays a material foundation for the effective development of various innovation activities. Supply-oriented policy instruments refer to the driving force of policy on innovation and development, which can be subdivided into infrastructure construction, personnel training, capital investment, information support, and public services. For instance, the industrial policy of new energy vehicles was introduced earlier and had better categories. From the perspective of enterprise financial support, in September 2017, the Ministry of Industry and Information Technology promulgated the “Parallel Management Measures for Average Fuel Consumption and Electric Vehicle Credit of Passenger Car Enterprises”. The enterprise is evaluated according to sales and average fuel consumption of electric vehicles. If the enterprise completes the relevant indices, its credit is positive and can obtain a certain amount of capital through a loan. From the technical support point of view, Wen Jiabao emphasized in the “Several Issues on Science and Technology Work” on July 6, 2011, that it is necessary to concentrate on investing funds and research efforts in strategic directional key common technologies. From the perspective of supporting infrastructure, on January 19, 2016, several ministries and commissions jointly issued the “Notice on the Incentive Policy of New Energy Vehicle Infrastructure and Strengthening the Promotion and Application of New Energy Vehicles during the 13th Five-Year Plan”, which provided support for the construction of charging piles and the operation of overall facilities in the next five years.

Environment-oriented policy instruments emphasize the government’s provision of a favorable external environment for innovation development through fiscal, tax, financial, legal, and other measures, providing a favorable macro guarantee for innovation activities. Environmental-oriented policy instruments can be further divided into target planning, fiscal and financial, tax incentives, regulatory control, and strategic measures. Taking the new energy vehicle policy as an example, the “Decision on Accelerating the Cultivation and Development of Strategic Emerging Industries” promulgated in October 2010 listed new energy vehicles as a strategic emerging industry. It promoted the importance of developing the new energy vehicle industry from a strategic perspective and provided superior support for the technical research, production, and application of related units. Furthermore, Article 4 of the “Vehicle and Vessel Tax Law of the People's Republic of China” passed on February 25, 2011, clearly stipulated the tax reduction and exemption policies of new energy vehicles, which reduced the burden for the development of the new energy automobile industry.

Demand-oriented policy instruments refer to the government's use of procurement, outsourcing, regulation, and other methods to reduce market uncertainty or create new markets, thus providing a stage for applying new technologies and products. Demand-oriented policy instruments reflect the driving force of policy on innovation and development, including government procurement, service outsourcing, trade control, and overseas institutions. Taking the new energy vehicle policy as an example, in June 2010, four ministries and commissions jointly issued the “Notice on Launching Pilot Subsidies for Private Purchase of New Energy Vehicles”, which announced different levels of consumption subsidies for private consumers of new energy vehicles in pilot cities. Furthermore, on June 28, 2011, the leaders of China and Germany issued the “Joint Statement on Establishing Strategic Partnership for Electric Vehicles between China and Germany”. It encouraged the enterprises and research institutes of both countries to exchange, cooperate and jointly promote the development of the electric vehicle industry.

Generally, supply-oriented policies guarantee the development foundation of the industry through the means of production, capital, conditions and other aspects of industrial production. Environment-oriented policies create favorable conditions for industrial development, including a friendly financial and political development environment, so that enterprises have laws and rules to follow and for planning clear development goals and strategies. Demand-oriented policies stimulate production by creating new demand, expanding existing demand and exploring potential demand from the perspective of industrial expansion and development. The policy instruments included in supply-oriented, environment-oriented and demand-oriented industrial policies are shown in Figure 1.

According to the definitions and characteristics of the above three industries, we classify the local ICV industry policies in Table II (see Table III for details).

TABLE III

| City     | Policy type       | Policy instrument       |
|----------|-------------------|-------------------------|
| Beijing  | Environment-oriented | Target planning         |
| Shanghai | Environment-oriented | Target planning         |
| Chengdu  | Environment-oriented | Target planning         |
| Changchun| Environment-oriented | Legal regulation        |
| Tianjin  | Environment-oriented | Legal regulation        |
| Changsha | Environment-oriented | Legal regulation        |
| Shenzhen | Environment-oriented | Legal regulation        |
| Jinan    | Environment-oriented | Legal regulation        |
It can be seen from Table 2 that most cities will choose to implement environment-oriented policies in the early stage of ICV industry development, when target planning and legal regulations are more commonly used policy instruments. Target planning generally refers to the country's comprehensive and long-term development vision, and legal regulation entails the regulatory measures to establish market norms, such as patent rights, intellectual property rights, and production access standards. Second, they will choose demand-oriented policies based on established instruments to promote demonstration projects or create demonstration areas. Supply-oriented policies are seldom used; apparently, they are not the first policy choice for cities in the early stage of development of the ICV industry. Existing studies have confirmed this phenomenon. Gu [33] showed that in China, where the level of independent technological innovation lags behind that of Western developed countries, an environment-oriented policy (especially intellectual property protection) could stimulate the independent innovation enthusiasm of the main body in the industry and may even cultivate independent innovation ability and promote innovation in the industrial field. However, vigorously implementing supply-oriented industrial policies such as government subsidies may inhibit innovation in the industrial field if the use of subsidies is unreasonable. Hu and Jiang [34] studied the Tianjin government's science and technology innovation policy from 2000 to 2019 and concluded that environment-oriented policy instruments are the main policy instruments. Wang and Yin [35] also pointed out that for the local industrial policy of new energy vehicles, the effect of the environment-oriented policy is more remarkable.

Environment-oriented policies have undeniable advantages in promoting the development of technological innovation industries. The traditional order of innovation technology policy is that the supply-oriented policy takes the first step, and the basic research and development of technology is promoted by instruments such as fund support and personnel training. Demand-oriented industrial policies will then be implemented to stimulate market demand, create opportunities for technology application and provide the power for industrial upgrading and technological progress. Finally, environment-oriented industrial policies are implemented to improve the ecological environment of the industry. However, as a technological innovation industry, ICV was born under the integration and development of vehicle electrification, communication and internet technologies; thus, there is no need for a long waiting period for research and development, and it is easy to form its own or even disruptive (such as legal transportation infrastructure information security and other aspects) application platform. For the ICV industry, the need for industry policy is more of a legal regulation, policy guide, and goal programming, such as environment-oriented policy. It can give full consideration to the planning target system by adopting the method of normative management by objectives. It pays attention to improving the implementation of the real planning target detail process to the policy instruments, cultivating industrial ecology, and eliminating concerns about technology development and application. Therefore, the ICV industry's features make the environment-oriented policy the forerunner in most cities. In addition, the situation of the ICV industry is highly similar to that of the new energy car industry. In summary, it can be reasonably assumed that the environment-oriented policy will have significant advantages for developing the ICV industry, which is also consistent with the dynamic illustrated in Figure 2.

### IV. MODEL DESIGN

We use the DID method to evaluate the innovation performance of local policies for ICVs. Considering that the implementation time of ICV policy is different in each prefecture-level city, the standard DID is insufficient; instead, we use the multiperiod DID that takes into account the different times of different policies. The DID estimation specification is as follows:

\[
Y_{it} = \alpha + \beta_1 \times Post_{it} \times Treat_i + \beta_2 \times Treat_i + \beta_3 \times Post_{it} + \gamma_i + \eta_i + \varepsilon_{it}
\]

where \(i\) represents cities and \(t\) represents years. \(Y_{it}\) is the innovation performance of ICV in prefecture-level city \(i\) at year \(t\), which is measured by the number of ICV patents. \(Post_{it}\) represents the dummy variable of policy time whether the local policy of ICV takes place; it is 0 before and 1 after the occurrence of the policy. Different from the standard DID, \(Post_{it}\) in the multiperiod DID is not the same for all cities. \(Treat_i\) indicates whether the prefecture-level city is in the treatment group. If the city issues the local ICV policy, then \(Treat_i\) is 1; otherwise, it is 0. \(Post_{it} \times Treat_i\) is the interaction term between \(Post_{it}\) and \(Treat_i\). If the city is in the treatment group and the ICV policy has been implemented, \(Post_{it} \times Treat_i\) is 1; in other cases, \(Post_{it} \times Treat_i\) is 0. In addition, we also control the year fixed effect \(\eta_i\) and city fixed effect \(\gamma_i\). The result of \(\beta_1\)'s estimation reflects the innovative performance of local policies for ICV. In the specific estimation, because the year fixed effect and the city fixed effect are controlled, \(Treat_i\) and \(Post_{it}\) will be ignored. \(\varepsilon_{it}\) is the error term. In the estimation, we clustered standard errors at the city level for all models.

The number of ICV patents in various prefecture-level cities is mainly used as data. Considering that the total

| Nanjing   | Demand-oriented | Demonstration project |
|-----------|-----------------|----------------------|
| Wuhan     | Demand-oriented | Demonstration project |
| Ningbo    | Demand-oriented | Demonstration project |
| Guangzhou | Demand-oriented | Demonstration area    |
| Suzhou    | Demand-oriented | Infrastructure       |
| Hefei     | Supply-oriented | Infrastructure       |

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number of ICV patents in China in 2015 and previous years is relatively small, we used the DI patent platform\(^1\) for patent data retrieval from 2016 to 2020. We searched for patents\(^2\) of ICV in Mainland China from 2016 to 2020 by year and used the method of zip code matching to obtain the patent location to obtain the number of intelligent connected vehicle-related patents in a city in the corresponding year. After removing the data that did not include the city name according to the zip code, 9,680 available patents were retrieved. The number of patents for each of the 257 cities over a five-year period was matched by zip codes. When grouping the treatment group and the control group, we found that a total of 14 cities implemented the ICV policy from 2016 to 2020. These 14 cities were the treatment group, and the remaining cities were the control group. The statistical sample data of the number of local patents granted in China (in no particular order) are shown in Table IV.

### TABLE IV
**STATISTICAL SAMPLE DATA OF THE NUMBER OF LOCAL PATENTS GRANTED IN CHINA**

| City     | 2016 | 2017 | 2018 | 2019 | 2020 | Total number of patents granted | The year of the first policy implementation |
|----------|------|------|------|------|------|---------------------------------|---------------------------------------------|
| Jinan    | 22   | 16   | 35   | 31   | 45   | 162                            | 2018                                        |
| Wuhan    | 23   | 38   | 63   | 58   | 78   | 268                            | 2016                                        |
| Shanghai | 32   | 48   | 84   | 75   | 70   | 327                            | 2016                                        |
| Beijing  | 150  | 186  | 293  | 294  | 244  | 1230                           | 2016                                        |
| Nanking  | 15   | 74   | 66   | 91   | 114  | 369                            | 2016                                        |
| Guangzhou| 43   | 72   | 97   | 109  | 122  | 459                            | 2017                                        |
| Changchun| 28   | 29   | 40   | 88   | 76   | 268                            | 2018                                        |
| Hefei    | 43   | 40   | 91   | 61   | 62   | 304                            | 2016                                        |
| Kunming  | 1    | 8    | 6    | 5    | 3    | 26                             | —                                           |
| chengde  | 0    | 0    | 0    | 0    | 2    | 2                              | —                                           |
| Guiyang  | 3    | 4    | 6    | 13   | 3    | 32                             | —                                           |

Note: The parentheses indicate the clustering robust standard error at the city level. ***p<0.01, **p<0.05, *p<0.1

### VI. PARALLEL TREND TEST AND DYNAMIC EFFECT ANALYSIS

A prerequisite for unbiased estimation by DID is that the treatment group and the control group meet the parallel trend hypothesis, that is, the treatment group and the control group should have the same change trend before the policy occurs. To test the parallel trend hypothesis of local ICV policies and explore the dynamic effect of the innovation performance of local ICV policies, we add a series of time dummy variables before and after the occurrence of policies in the main DID estimation model. The model of the parallel trend test is as follows:

\[
Y_{it} = \alpha + \beta_{-3} \times P_{it}^{-3} \times \text{Treat}_i + \beta_{-2} \times P_{it}^{-2} \times \text{Treat}_i + \beta_{0} \times P_{it}^{0} \times \text{Treat}_i + \ldots + \beta_{k} \times P_{it}^{k} \times \text{Treat}_i + \gamma_i + \eta_i + \epsilon_{it} 
\]

(2)

where \(P_{it}^{-k}\) and \(P_{it}^{k}\) are time dummy variables. In k years before the implementation of local ICV policies, \(P_{it}^{-k}\) is 1, and in other cases, it is 0. In k years after implementing local ICV policies, \(P_{it}^{k}\) is 1, and in other cases, it is 0. We also control the year fixed effects \(\eta_i\) and the city fixed effects \(\gamma_i\). \(\epsilon_{it}\) is the error term. The robust standard error of clustering at the city level is used in the estimation.

\(\beta_{k}\)'s estimated results reflect the parallel trend before ICV policy, \(\beta_{k}\) reflects the dynamic situation of innovation effect after the ICV policy. If the cross-item estimation effects, respectively. The estimation result of the cross-term coefficient reflects the policy effect. Table V shows that the innovation effect of local ICV policies is significant at the 5% level, regardless of whether the fixed effect is controlled. From the cross-term coefficient and standard error in Column (4), it can be concluded that the 95% confidence interval for the innovation effect of local ICV policies was 1.446 to 35.027 patents. Generally, we think that local ICV policies have significantly promoted the related innovation of regional ICVs.
effect is not significant at the 5% level in the years before the occurrence of the local ICV policy, the parallel trend test is satisfied. This indicates that the DID method is applicable.

The parallel trend test estimation results of the innovation effect of local ICV policies are shown in Table VI. Column (1) is the estimation result of the parallel trend test for controlling city fixed effects and year fixed effects. With reference to conventional practice, we take the year before the occurrence of the policy as the base period. The estimation results of the cross-term coefficients before the policy occurrence reflect the parallel trend. It can be found that the cross-term coefficients of the two years before the policy occurred and the three years before the policy occurred are not significantly different from zero at the 5% level. We believe that the DID method used in this paper meets the parallel trend test.

The estimated results of the cross-term coefficients over the years after policies reflect the dynamic effect of the innovation effect of local policies for ICVs. It is found that the local ICV policies show lagging policy effects. In the first year of the policy, the prefecture-level cities in the treatment group did not show significant policy effects. With the promotion of the policy, there was a significant policy effect at the 10% level in the second year of the policy. Then, in the third, fourth and fifth years of the policy, the policy effect became more significant and stable. The estimated coefficient was significant at the 1% level for both years, and the policy effect remained stable for approximately 45 patents. In summary, it can be concluded that the local policy innovation effect of ICV has a lag of 1–2 years, but the policy effect is strong and lasts for at least 3 years.

### Table VI

| Parallel Trend Test and Dynamic Effect Analysis | (1) |
|-----------------------------------------------|-----|
| **Parallel trend**                            |     |
| 3rd year before the policy occurred           | -28.965*** |
| 2nd year before the policy occurred           | -1.792 |
| 1st year of policy occurrence                 | 2.173 |
| 2nd year of policy occurrence                 | 15.680*** |
| **Dynamic effect**                            |     |
| 3rd year of policy occurrence                 | 34.393*** |
| 4th year of policy occurrence                 | 50.839*** |
| 5th year of policy occurrence                 | 48.905*** |
| Year fixed effects                            | YES |
| City fixed effects                            | YES |
| R2                                            | 0.294 |
| Number of Observation                         | 1280 |

Note: The parentheses indicate the robust standard error of clustering at the city level, ***p<0.01, **p<0.05, *p<0.1.

### VII. ROBUSTNESS TEST

In the above DID model, to make statistical inferences on the estimated ICV policy effect, we need to impose certain assumptions on the error term. However, the real correlation between error terms is unknown, so various calculation methods of robust standard errors are developed, such as the clustering robust standard errors used in this paper. In this situation, choosing any robust standard error may not lead to an unbiased standard error. Thus, we use an approximate permutation test to obtain statistical inferences of policy effects that do not require assumptions on the error terms.

Specifically, we obtain the empirical distribution of the local ICV policy effects by randomly setting virtual policies. The specific steps are as follows. Step 1: 14 cities are randomly selected as a virtual treatment group in all cities. Step 2: For each virtual city in the treatment group, one year is randomly selected as the virtual year of policy implementation of this city between 2016 and 2019. Step 3: Based on the virtual treatment group and the virtual implementation year of the policy, the DID model in this paper is used to estimate the virtual policy effect. Step 4: Repeat the process 9,999 times.

We obtained 10,000 policy effects through 9,999 simulations, plus one real natural experiment in this paper. Based on 10,000 policy effects, we obtain the empirical distribution of policy effects. At this point, we can obtain the statistical inference result of the real policy effect evaluated from the natural distribution. Figure 2 is the empirical distribution of policy effects, and the red line in the figure is the real policy effects (the policy effects in Column (4) in Table 4, i.e., Line X=18.237). Among the 10,000 policy effects, only 10 virtual policy effects are greater than the 18.237 estimated in this paper, so we infer that the P value is 0.001%. In other words, the policy effect of local ICV policy is still significant without the assumption of the error term.

### VIII. CONCLUSION AND INSIGHTS
In this paper, we studied the impact of China's ICV policy on innovation performance. First, compared with the ICV policies in the United States, the European Union, Japan and other developed countries, it is found that China initiated its ICV strategic planning later. However, since 2015, China has launched a number of policies that strongly support the development of the ICV industry, which is gradually maturing. Second, we sorted out the first ICV policies in 14 first-tier cities and divided them into three types: demand-oriented, supply-oriented and environment-oriented policies. We further analyzed the policy instruments they used. Finally, we studied the impact of the first local ICV policy on innovation performance by using patent data from Chinese prefecture-level cities from 2016 to 2020. We found that the cities that issued the local policies of ICV earlier are first-tier cities with developed economies and large populations, such as Beijing, Shanghai and Wuhan. At the initial stage of developing the local ICV industry, these cities are more likely to choose an environment-oriented industrial policy represented by target planning and legal regulation as the first local ICV industrial policy. The local industrial policy of ICV has a significant incentive effect on the innovation of the local intelligent connected vehicle industry; the policy has no lag and has good continuity. The average innovation effect of local ICV policies is approximately 18 patents. In the third year, the ICV policies began to take effect. The innovation effect is stable at approximately 45 patents. The first batch of cities to implement local policies have become the leading cities in China's ICV industry due to the promoting effect of the ICV policies on the development of local industries. To ensure the rigor of the experiment, robustness, parallel trend, and dynamic effect analyses are carried out. The results of the robustness test show that the policy effect of the local ICV industrial policy is still significant when no assumption is imposed on the error term. The results of the parallel trend test showed that the experimental group and the control group had good consistency before the policy was issued. The results of the dynamic effect analysis show that the local policy innovation effect of ICV has a lag time of 1–2 years, but the policy effect is strong and lasts for at least 3 years.

Based on the above research conclusions, we propose the following recommendations. First, we should strengthen planning guidance and top-level design. Comprehensive consideration should be made of China's industrial foundation and development potential, road traffic environment, laws and policies, information security guarantee system, consumption and use environment, key technology breakthroughs, industrialization goals, etc. From the top design of the ICV industry development plan, China should clarify the key driving factors of industrial development, build the overall development strategy and policy system of ICVs in line with its national conditions, build a cross-department coordination mechanism, and promote the common development of ICVs and related industries. Second, we should improve the legal environment by carrying out in-depth research on laws and regulations facing the development of ICVs and accelerating the removal of road-related driving, information security and other legal and regulatory obstacles. Third, we should strengthen research and development innovation, which entails strengthening the research and development of key common core technologies of ICV, focusing on key problems, accelerating breakthroughs in key and core technologies, promoting the building of basic data exchange platforms and industrialization service platforms and supporting the coordinated development of the industrial chain. In general, other prefecture-level cities in China can refer to first-tier cities for their industrial policies in the early stage of ICV industry development, choose environment-oriented policies represented by target planning and legal regulation, and promote rapid and high-quality industrial development by promoting industrial innovation.

Of course, there are still many limitations in this study. In the future, based on this research, the scope of the study can be further expanded to more cities as samples to assess policy effects more accurately. We believe that future directions include the following points: (1) What are the channels of influence of ICV policies to improve a city’s ICV patents? (2) Do ICV policies have an impact on a city’s ICV innovation efficiency, ICV patent quality, and ICV patent structure, in addition to increasing the number of ICV patents? (3) Is there heterogeneity of ICV policy effects in different cities? The effect of ICV policies will be further analyzed in the future by trying to answer the above questions.

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