Economic Systems 47 (2023) 101049

Contents lists available at ScienceDirect

Economic Systems

journal homepage: www.elsevier.com/locate/ecosys

Debt financing and maintenance expenditure: Theory and evidence on government-operated toll roads in China

Jiandong Chen[a], Jie Yu[a], Zhiyang Shen[b], Malin Song[c,*], Ziqi Zhou[d]

[a] School of Public Administration, Southwestern University of Finance and Economics, Chengdu, China
[b] IESEG School of Management, Univ. Lille, CNRS, UMR 9221 - LEM - Lille Economie Management, F-59000 Lille, France
[c] School of Statistics and Applied Mathematics, Anhui University of Finance and Economics, Bengbu, China
[d] College of Arts and Science, The Ohio State University, Columbus, United States

A R T I C L E I N F O

JEL classification in this article:
H41
H53
H63
R42

Keywords:
Toll roads
Tollway bond
Debt financing
Maintenance expenditure

A B S T R A C T

Transportation infrastructure is the foundation of economic growth, and the existence of high-quality roads is inseparable from their durable maintenance. However, the burden of heavy debt has brought risks to maintenance management and distorted resource allocation. This study builds a two-stage optimal theoretical model under different debt-financing constraints in China, who has the longest expressway mileage of any country in the world. We establish the two principles of "spend-and-debt" and "debt-and-spend" to demonstrate the substitution effect and the complementary effect of debt financing on maintenance, respectively. Furthermore, we use a time-varying differences-in-differences approach to estimate the effect of the financing of tollway bonds on maintenance and further discuss the mechanism. The results provide evidence that there is a significant improvement in the relationship between tollway bonds and maintenance expenditure, mainly due to the reduction of debt costs and the passive propelling of the government's spending responsibility. Our proposed theoretical and empirical framework sheds new light on transportation infrastructure research. More specifically, the impetus for public expenditure comes from a decrease of the substitution effect, which not only alleviates the burden of debt scale on the public sector but also provides a reference for developing countries to balance infrastructure construction and maintenance.

1. Introduction

Transportation infrastructure is often regarded as the key to promoting economic growth (Banerjee et al., 2020). With the improvement of China's highway network, maintenance management is the focus of attention at present and is expected to remain so in the future. Based on China's past model of loans for road construction and toll repayment, local governments focused their efforts on construction through loan financing to improve dominant political performance, and the revenue from toll roads was used almost entirely for loan repayments in addition to guaranteeing necessary maintenance expenditure. Since there are serious gaps between

* Corresponding author.
E-mail addresses: z.shen@ieseg.fr (Z. Shen), songmartin@163.com, songmartin@yeah.net (M. Song).

https://doi.org/10.1016/j.ecosys.2022.101049
Received 22 June 2021; Received in revised form 7 June 2022; Accepted 8 June 2022
Available online 21 September 2022
0939-3625/

revenue and expenditure, there is no guarantee that there will be sufficient funds to maintain the budget (Brach and Wachs, 2005), which increases maintenance pressure on local governments. However, the pursuit of rapid economic growth in developing countries has led to an unbalanced situation of focusing on construction and neglecting maintenance.

Road maintenance is an important expenditure of public transport on governments (Bock et al., 2021). According to the National Bureau of Statistics (NBS), China has the longest expressway mileage of any country in the world, reaching around 161,000 kilometers in 2020 and surpassing the mileage expressway of the United States.[1] China's toll roads are mainly expressways. The maintenance management of China's expanded toll road network will become heavier in the future, and capital investment demand for maintenance work will gradually increase (Heggie, 1999). The construction of highway infrastructure is an explicit cost, while maintenance is an implicit cost. The scale of maintaining infrastructure is smaller and less obvious than that of new infrastructure (Zietlow, 2006). The *Thirteenth Five-Year Plan Highway Maintenance Management Development Outlin*e mentioned that the main contradiction of China's highway development has changed from that between demand for and insufficient supply of infrastructure to a new contradiction in which public service capacity is not compatible with social requirements. Maintenance expenditure is a guarantee for the high-quality development of highways, which is a long-term expenditure. To achieve high-quality development of highway infrastructure, it is necessary to attach importance to road maintenance issues and to transition gradually from traditional passive maintenance to modern maintenance, that is, preventive maintenance, which meets the requirements of social development. However, toll roads still face such problems as high maintenance costs, limited funding sources, and heavy burden of local loan repayment debts, which has led to the maintenance of road quality and benefits being ignored. Therefore, under different debt-financing patterns, the impact of the road debt scale on maintenance expenditure should be paid attention.

Research on highways mainly focuses on the following topics. The first is the trade-off between construction and maintenance from a macro perspective (Rioja, 2003; Kalaitzidakis and Kalyvitis, 2004; Agénor, 2009; Jullien et al., 2014). The second topic is road pricing and tolls (Ferrari, 2002; Xu et al., 2017; Hall and Savage, 2019; de Dios Ortúzar et al., 2021). The third topic is discussion of roads externalities. On the one hand, tolls can solve the problem of resource misallocation, have positive externalities (Rouwendal and Verhoef, 2006; Hamilton and Eliasson, 2013; Santos, 2017; Andani et al., 2019), and greatly improve road infrastructure (Bogart, 2009). On the other hand, the external cost (i.e., negative externalities) of toll roads is discussed (Calthrop and Proost, 1998; Cravioto et al., 2013). The fourth topic is the impact of transportation infrastructure on welfare (De Soyres et al., 2020; Shamdasani, 2021). The fifth topic is contracts for toll roads (Anastasopoulos et al., 2010; Song et al., 2018) and operational cost of toll roads (Odeck, 2019). Overall, the literature review shows that the revenue and expenditure and economic impact of highways have been the subject of long-term and meaningful research. In addition, existing literature on maintenance focuses on the optimization of road maintenance, including Harvey (2012), Moreno-Quintero et al. (2013), and Mathew and Isaac (2014). López-Pita et al. (2008) analyzes maintenance costs of high-speed lines. However, few studies combine government debt with infrastructure maintenance.

Fortunately, China's tollway bonds open a new horizon for public sector to debt-financing and provide an opportunity for research on the maintenance of transportation infrastructure. Restricted by empirical data, the current research is limited to qualitative research and theoretical discussion. Few studies have conducted theoretical discussion and empirical estimation on the debt financing of toll roads and the importance of road maintenance. Based on the budget constraints established by different stages of financing models, we explore the financing of tollway bonds and maintenance expenditure. There is an urgent need to deliberate on whether huge debt scale leads to heavy repayment pressure, and whether there would be substitution effect and complementary effect on public expenditures (e.g., maintenance expenditure). Shedding light on these questions would not only enrich the theory of public goods charges but also help the public sector to raise infrastructural funds as a reference, which would avoid distortions in resource allocation in developing countries.

This study contributes to the literature on public maintenance expenditure in the following three ways. First, this study constructs a theoretical model of tollway bonds on toll roads. According to the distinct financing models of government-operated toll roads and different toll goals, we propose a two-stage optimal theoretical model. One is summarized as "spend-and-debt" and the other as "debt-and-spend." The models are established to demonstrate the substitution effect and complementary effect of debt financing on maintenance, respectively. Second, there is currently a lack of research on special tollway bonds. Due to the data limitations, existing literature focuses on qualitative research and theoretical discussion. Based on the advantages of the data, the empirical analysis further supports the theoretical hypothesis. We use time-varying differences-in-differences (DID) to estimate the effect of the tollway bonds on maintenance expenditure in China, and provide evidence that the implementation of tollway bonds can reduce the cost to some extent, relieve the burden of debt, and significantly promote the level of maintenance expenditure. The third contribution is that we explore the impact mechanism of tollway bonds on maintenance expenditure. We obtain a very interesting conclusion that the increase in maintenance expenditure is mainly driven by the passive maintenance of the local government. The reason for the significant effect is a reduction of the substitution effect rather than an increase of the complementary effect. This exploration explains the relationship between the debt financing model and public maintenance expenditure corresponding to the theoretical hypothesis, which not only helps balance construction and maintenance but also provides a reference for developing countries to avoid distortions in resource allocation.

The remainder of the paper proceeds as follows. Section 2 presents background and factual characteristics. Section 3 construct the two stages of the theoretical model. The data and empirical estimation are presented in Section 4. Section 5 presents and discusses the empirical results. Section 6 concludes.

[1] The United States data are from the *Federal Highway Administration*.

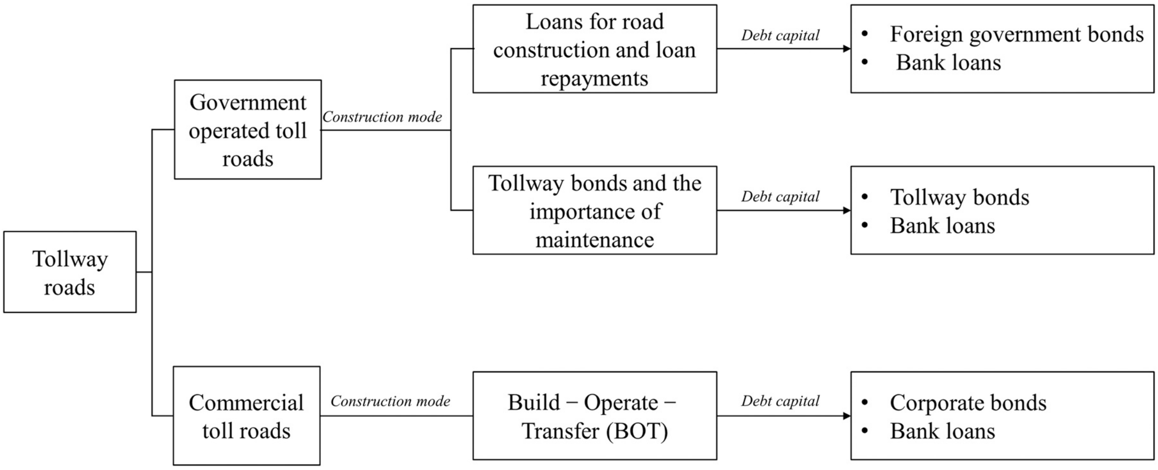

Fig. 1. The construction mode and debt financing of toll roads in China.

2. Institutional background

2.1. Debt financing of toll road

In December 1984, China approved the introduction of a toll roads policy involving loans for road construction and toll repayment. This policy ended the mechanism of road construction that relied solely on public financing and established a diversified investment and financing pattern of national investment, local financing, social financing, and use of foreign capital, which has greatly promoted the construction and development of highway infrastructure. However, the long-term loan-to-road construction model has increased loan repayment pressure and debt risks of Chinese local governments, and the high level of debt has led to a gradual increase in revenue and expenditure gaps in most provinces. The aim is to avoid the risk of local debt caused by loans for road construction at the source, optimize the allocation of resources, and further improve the quality and service of toll road infrastructure. In June 2017, the Ministry of Finance and the Ministry of Transport jointly issued the *Administrative Measures for Special Bonds for Local Government-Operated Toll Roads*, which ended the long-standing investment and financing pattern of unified loans and repayments in China. The measures stipulate the establishment of pilot projects in the field of government-operated toll roads, the issuance of tollway bonds, and the gradual expansion of the scope of the trial from 2017. The notice means that tollway bonds are the only way for the government to build toll roads to solve the problem of debt financing.

There are two types of toll roads in China: government-operated toll roads; and commercial toll roads. The two types are distinguished by the ownership of the operators. In the past, toll roads in China were mainly government-operated toll roads, and the mileage of commercial toll roads will gradually exceed the mileage of government-operated toll roads from 2020. The mileage of government-operated toll roads amounted to 83,600 kilometers in 2020, while that of commercial toll roads was 95,700 kilometers. Fig. 1 shows the differences between the construction mode and debt financing of government-operated toll roads and commercial toll roads. As the figure shows, different types of toll roads have different construction modes. The public sector is responsible for government-operated toll roads, while the private sector is responsible for commercial toll roads. Toll roads have different financing models (Yan et al., 2017), this study divides toll roads into two stages according to the different debt-financing models of government-operated toll roads.

The first stage is the construction mode of loans for road construction and loan repayment to solve the burden of debt repayment by charging vehicle tolls; that is, the debt scale is determined according to the construction scale, which can be regarded as a "spend-and-debt" model (1988–2016). In the second stage, government-operated toll roads follow the goal of tollway bonds with importance on maintenance to realize a powerful transportation network in China; that is, deciding how many roads to build based on how much debt is issued can be regarded as "debt-and-spend" model (2017–present).

Not to mention, most construction modes of commercial toll roads adopt the build–operate–transfer (BOT) model. As the public sector is subject to budget constraints, it gradually raises funds from the private sector, and public–private partnerships (PPPs) have become a popular strategy (Kaminsky, 2018; Jin et al., 2020). However, PPPs fail to construct and operate highways if demand is lower than expected (Menezes and Ryan, 2015). Therefore, government bonds are a necessary financing channel for the public sector when the budget cannot make ends meet. Local governments borrowed debt for the development of government toll roads by issuing special bonds, and this study mainly discusses government bonds for government-operated toll roads, that is, tollway bonds.

2.2. Tollway bonds and loans

Tollway bonds are a category of local government special bonds. Debt capital consists of bank loans and bonds, both of which constitute a source of local government debt (Chen et al., 2020). According to the classification framework of the *Toll Roads Statistical*

Bulletin, the construction investment funds are mainly derived from fiscal capital, non-financial capital (e.g., social capital and enterprises and institutions), bank loans, and other debt (e.g., issuance of bonds, foreign borrowing). The difference between loans and bonds is that the loan funds come from domestic financial institutions, and the bond issuance belongs to the government debt issued by the government through the investment and financing platform. Therefore, there are certain differences between the financing objects and their financing channels. However, in different stages, bonds further regulate the financing channels of toll roads. For example, the debts of the first stage include foreign government bonds, and those of the second stage have clearly eliminated such sources.

Based on the data of the *China Electronic Local Government Bond Market Access*, as of 2021, the total issuance of tollway bonds reached 617.14 billion yuan. However, the importance of bond issuance has gradually been manifested from the perspective of growth rate. For example, at the end of 2013, the balance of bonds accounted for 5.6% of the balance of loans, while the balance of debt at the end of 2020 accounted for closing to 21% of the loan amount.[2] It is important to note that the balance of bank loans and debt are cumulative balance, and the reason why the debt balance accounts for a relatively low proportion is that the debt capital before the implementation of the policy is mainly bank loans. The reason why the current cumulative balance of loans is still high is that the bank loans have not been paid off. At the same time, with the implementation of the *Budget Law of the People's Republic of China* revised in 2014, it means that the government-operated toll roads will no longer rely on bank loans to finance new toll roads, and the tollway bonds will be the only way for the government-operated toll roads to solve the problem of debt financing. The above data show that the tollway bond has gradually become the important source of debts among government-operated toll roads, and the proportion continues to increase gradually. At the same time, to distinguish the policy effects of bonds in debt capital financing, this study controls the proportion of loan capital to the cumulative total capital in the empirical analysis, so as to eliminate the interference of loan proportions on the policy effects of highway bonds.

Tollway bonds use the book-entry fixed interest rate payment form, and the issuance rate is low relative to the loan interest rate. This improves not only the standardization and orderliness of funds but also the efficiency of the use of highway construction capital. However, due to the randomness of bank loans by some governments, the loan scale has increased, and the financing cost of bank loans has been high, causing excessive pressure on the government to repay the loan interest. Therefore, government-operated toll roads are financed by issuing as much debt as it takes to build as many roads as possible, which can control the scale of debt and prevent debt risks.

3. Theoretical model

3.1. Two-stage budget and debt constraints for toll roads

Government-operated toll roads are represented by g, commercial toll roads are represented by c, and the toll roads discussed in the following are mainly government-operated toll roads. If not specifically referred to c, generally refer to government-operated toll roads.

To facilitate calculation and understanding, we divide the life cycle of toll roads into two periods: the construction period; and the operation period. The total life cycle $l = \{1, \ldots, l, \ldots, L\}$ is available, that is, the construction period $t = \{1, \ldots, t, \ldots T\}$ and the operation period $s = \{T+1, \ldots, s, \ldots, S\}$ distribute the whole life cycle, so that $T \subset L$, $S \subset L$, $T + S = L$ and $T \cap S = \emptyset$. Therefore, the life cycle can be divided into two different budget constraints throughout the construction period and the operation period.

3.1.1. Loans for road construction and toll repayment

In the first stage, the vehicle tolls for government-operated toll roads must be used for loan repayments except for the necessary management and maintenance costs, which are included in the vehicle toll budget approved by the Ministry of Finance in China. In addition, the *People's Republic of China Highway Law* stipulates that in addition to the government fiscal subsidy, the funds raised for road construction can be obtained via loans from domestic and foreign financial institutions or foreign governments. The funding sources for government-operated toll roads in this stage mainly include the following: fiscal subsidy, social investment, loans from domestic and foreign financial institutions, domestic and foreign government debt, and vehicle toll revenue.

The total construction is expressed as $G_{t,1}$, where sources of funds are owned capital and debt capital. Fiscal subsidy and social investment are collectively referred to as owned capital $F_{t,1}$, and loans from domestic and foreign financial institutions and government debt are referred to as debt capital ($B_{t,1}$). Considering the principle that toll roads are built with loans, the total capital during the construction period can be expressed as $\sum_{t=1}^{T} G_{t,1} = \sum_{t=1}^{T} (F_{t,1} + B_{t,1})$. The source of capital for toll roads during the operating period includes vehicle toll revenue (I_s), and fiscal capital, such as transfer payments. Since fiscal capital is exogenous variable, we do not consider fiscal capital when constructing the model. In terms of expenditure, $E_{s,1}$ is used to indicate the expenditure of toll roads during the operating period, including road maintenance $M_{s,1}$, debt principal and interest ($D_{s,1}$), and other expenditures ($O_{s,1}$), which can be defined as $\sum_{s=T+1}^{S} E_{s,1} = \sum_{s=T+1}^{S} (M_{s,1} + D_{s,1} + O_{s,1})$.

Assuming that government debt extension is not allowed, the phenomenon of borrowing new debt to repay old debt still occurs. When debtors are unable to fulfill their current debts, they can only rely on refinancing to fulfill their payment commitments and use the method of borrowing new debt to repay old debt to continuously roll over snowballing debt. Therefore, the debt constraint of the

[2] The data are from the *Toll Roads Statistical Bulletin* in China.

local government can be set as the sum of the principal and interest of the debt during the construction period and less than the sum of the debt repayment during the operation period, namely, $\sum_{t=1}^{T}(1+r)^t B_{t,1} \le \sum_{s=T+1}^{S} D_{s,1}$. This illustrates that the loan capital obtained during the construction period are less than the pressure of the sum of the principal and interest of debt repayment in the operating period. Therefore, the debt constraint for the entire life cycle can be expressed as $\sum_{l=1}^{L}(1+r)^l B_{l,1} = \sum_{s=T+1}^{S} D_{s,1}$.

Regardless of the construction period or the operation period, the total revenue of the two highway phases is always equal to the total expenditure of the two phases in terms of the entire life cycle. The left side of Eq. (1) is the total capital of the two periods, owned capital $F_{t,1}$, construction period debt capital $B_{t,1}$, operating period debt capital $B_{s,1}$, and vehicle toll income $I_{s,1}$. The right side of Eq. (1) is the total expenditure of the two periods, which includes not only construction expenditure $G_{t,1}$, but also maintenance expenditure $M_{s,1}$, debt repayment $D_{s,1}$, and other expenditures $O_{s,1}$. Among them, r_1 is the interest rate of the first stage, and entire life cycle (l) contains construction period (t) and operating period (s). Therefore, the budget and debt constraints faced by local governments in the first stage can be expressed as

$$\begin{cases} \sum_{t=1}^{T}(F_{t,1}+B_{t,1}) + \sum_{s=T+1}^{S}(I_{s,1}+B_{s,1}) = \sum_{t=1}^{T} G_{t,1} + \sum_{s=T+1}^{S}(M_{s,1}+D_{s,1}+O_{s,1}) \\ \sum_{l=1}^{L}(1+r_1)^l B_{l,1} = \sum_{s=T+1}^{S} D_{s,1} \end{cases} \tag{1}$$

respectively, where, the subscript $_1$ indicates that the variables belong to the first stage.

3.1.2. Tollway bonds and the importance of maintenance management

With the deepening of the reform of the fiscal and taxation system and the new requirements of the reform of the investment and financing system in China, the debt financing of government-operated toll roads has gradually entered the track of rule of law. *The Budget Law of the People's Republic of China* revised in 2014 mentioned that part of the capital necessary for construction investment in the budget of provinces, autonomous regions, and municipalities can be issued within the limit determined by the State Council, and local governments are financed by debt bonds. However, local governments and their departments should not borrow any debt. Tollway bonds have gradually been piloted since 2017. If the prefecture-level government really needs to issue tollway bonds, the provincial government would agree to issue them and on-lend to the municipal governments. Tollway bond capital should be used exclusively for the construction of government-operated toll roads, not for the construction of non-toll roads, running expenses, or maintenance expenses, and a single issuance period should not exceed 15 years. The earlier provisions of the *People's Republic of China Highway Law* on the financing modes of domestic and foreign financial institutions or foreign government debts have been canceled. Currently, issuing tollway bonds is the only way to solve the problem of debt financing.

The difference from the previous stage is that tollway bonds in this stage are expressed by $B_{t,2}$. The total investment during the construction period can be expressed as $\sum_{t=1}^{T} G_{t,2}$. The total expenditure during the operating period is still available $\sum_{s=T+1}^{S} E_{s,2} = \sum_{s=T+1}^{S}(M_{s,2}+D_{s,2}+O_{s,2})$, and the difference from the first stage is that the debt principal and interest is represented by $D_{s,2}$.

Assuming that government debt extension is not allowed in the second stage, there are strict budget constraints restricting borrowing new debt to repay old debt, and determining the construction based on debt, which can be regarded as "debt-and-spend." If the current vehicle toll revenue is greater than or equal to the amount of debt repayment in the current period, it indicates that the debt risk is in a controllable state, that is, $\sum_{t=1}^{T}(1+r_2)^t B_{t,2} = \sum_{s=T+1}^{S} D_{s,2}$ indicate that there is no borrowing of new debt to repay old debt during the operating period.

The total revenue of the two phases of the highway always equals the total expenditure of the two phases in terms of the entire life cycle. The left side of Eq. (2) is the total capital of the two periods, owned capital $F_{s,2}$, construction period debt capital $B_{t,2}$, and vehicle toll income $I_{s,2}$. The right side of Eq. (2) is the total expenditure of the two periods, which includes not only construction expenditure $G_{t,2}$, but also maintenance expenditure $M_{s,2}$, debt repayment $D_{s,2}$, and other expenditures $O_{s,2}$. Among them, r_2 is the interest rate of the second stage. Therefore, the budget and debt constraints faced by local governments in the second stage can be expressed as

$$\begin{cases} \sum_{t=1}^{T}(F_{t,2}+B_{t,2}) + \sum_{s=T+1}^{S} I_{s,2} = \sum_{t=1}^{T} G_{t,2} + \sum_{s=T+1}^{S}(M_{s,2}+D_{s,2}+O_{s,2}) \\ \sum_{t=1}^{T}(1+r_2)^t B_{t,2} = \sum_{s=T+1}^{S} D_{s,2} \end{cases} \tag{2}$$

respectively, where subscript $_2$ indicates that the variables belong to the second stage.

3.2. Welfare maximization for government-operated toll roads

3.2.1. First stage of social welfare maximization

Assuming that consumers are homogeneous and provide club goods without differentiation, let $q$be the road traffic flow. y represents the capacity of toll roads, which reflects the capacity and service level of the road. Under normal operating conditions, when the traffic flow is far less than or close to capacity ($q \le y$), it indicates that the road has capacity to bear the traffic flow. When q is more than ($q > y$), there is traffic congestion. Therefore, the value range of traffic flow is $0 < q \le y$, which is an exogenous parameter in this model. Calthrop and Proost (1998) summarize the social cost of transportation into four aspects, including travel time cost, opportunity cost, accident cost, and air pollution cost. This study does not consider the opportunity cost of road users (e.g., fuel) or externality costs (congestion and environmental costs). We draw on the research of Shi et al. (2016), and let the inverse demand function d^{-1} be expressed as the sum of the toll rate and the travel time cost (see Eq. (3)). Among them, P_1 denotes the toll rate, which is affected by $B_{l,1}$, because tolls are to repay debts; $T(q)$is the travel time cost of road users, which is affected by q. The inconsistency with the setting of Shi et al. (2016) is that the travel time value β is omitted, and the expression is shown as

$$d^{-1}(q) = P_1(B) + T(q) \tag{3}$$

We standardize the total road users to 1. As we know, the consumer surplus (CS) is equal to the difference between the utility function of road users (the highest willingness to pay of road users) and the actual cost (vehicle traffic cost). Thus, the consumer surplus of toll road users can be expressed as Eq. (4), which shows that the consumer surplus is not only related to q, but also to P.

$$CS_1(P, q) = \sum\nolimits_{s=T+1}^{S} \int_0^y P_1(B) + T(q)dq - q \times P_1(B) \tag{4}$$

Assuming that different levels of toll roads use a uniform toll rate P, the traffic flow q can also reflect the road capacity. Vehicle toll revenue is represented by the product of the toll rate P_1 and the traffic volume q in Eq. (5), and thus, $I_{s,1}$ is also a function of $B_{l,1}$, which does not consider the reduction of vehicle fees, advertising revenue, and other service revenue.

$$\sum\nolimits_{s=T+1}^{S} I_{s,1}(B) = \sum\nolimits_{s=T+1}^{S} q \times P_1(B) \tag{5}$$

The scale of maintenance expenditure $M_{s,1}$ during the operation period is determined by the vehicle tolls $I_{s,1}$, which can be expressed as $M_{s,1}(I)$ where $M_{s,1}$ is an increasing function of $I_{s,1}$. As $I_{s,1}$ increases, the index invested in $M_{s,1}$ also increases. At the same time, the $I_{s,1}$ affects the scale and speed of $D_{s,1}$. However, a situation arises of borrowing new debt to repay old debt, and $D_{s,1}$ is determined not only directly by $I_{s,1}$, but also indirectly by $B_{l,1}$. Thus, $(\partial D_{s,1}/\partial I_{s,1})\cdot(\partial I_{s,1}/\partial B_{l,1}) = (1 + r_1)^l$, which highlights the charging of tolls for the repayment of debt. In this stage, the total expenditure of the operating period can be defined as Eq. (6).

$$\sum\nolimits_{s=T+1}^{S} E_{s,1}(B, I(B)) = \sum\nolimits_{s=T+1}^{S} (M_{s,1}(I(B)) + D_{s,1}(I(B)) + O_{s,1}) \tag{6}$$

Government-operated toll roads are public sector investments. Compared with pure public goods, toll roads are club products. As a supplier of toll roads, the public sector provides club products by charging users. The public sector, as a producer of toll roads, has three types of revenue and expenditure, namely, balance, surplus, and revenue and expenditure gap. To measure the level of producer welfare in the public sector, it is necessary to measure profit during the operation period. To simplify the model, we express the profit of the public sector as the difference between vehicle toll revenue and road expenses (Winston and Yan, 2011), and the producer surplus (PS) as equal to the profit of the public sector. $R_{s,1}$ is used to represent the profit of the government-operated toll roads in Eq. (7). Here, the public sector might not consider taxes and fees.

$$PS_1 = \sum\nolimits_{s=T+1}^{S} R_{s,1}(B, I(B)) = \sum\nolimits_{s=T+1}^{S} (I_{s,1}(B) - E_{s,1}(B, I(B))) \tag{7}$$

The social welfare maximization W_1 is the addition of CS and PS. CS is given by Eq. (4), and PS by Eq. (6). Therefore, simplified W_1 equals the utility of road users less the expenditure of the public sector during the operation period, as shown in Eq. (8).

$$W_1(B, I(B)) = CS_1 + PS_1 = \sum\nolimits_{s=T+1}^{S} \left(\int_0^y P_1(B) + T(q)dq - (M_{s,1}(I(B)) + D_{s,1}(I(B)) + O_{s,1}) \right) \tag{8}$$

The first-order derivative of the social welfare function with respect to the variables can be expressed as in Eq. (9).

$$\begin{aligned} &\partial W_1/\partial B_{l,1} = y\cdot(\partial P_1/\partial B_{l,1}) - (\partial M_{s,1}/\partial I_{s,1})\cdot(\partial I_{s,1}/\partial B_{l,1}) - (1 + r_1)^l \\ &\partial W_1/\partial I_{s,1} = y/q - (\partial M_{s,1}/\partial I_{s,1}) - (\partial D_{s,1}/\partial I_{s,1}) \end{aligned} \tag{9}$$

To explore the optimal scale of the first stage, it is necessary to discuss the maximization of social welfare under budget constraints. The debt problem of government-operated toll roads in the first stage is of the "spend-and-debt" type, and the debt scale is determined according to the construction. Given $\sum_{l=1}^{L} (1 + r)^l B_{l,1} = \sum_{s=T+1}^{S} D_{s,1}$, the budget constraint is the identity of income and expenditure during the operating period in Eq. (1), and i represents different provinces. Then, we have the Eq. (10).

$$\begin{aligned} &Max \sum\nolimits_{i=1}^{n} W_1(B, I(B)) \\ &s.\ t.\ \sum\nolimits_{t=1}^{T} G_{t,1} + \sum\nolimits_{s=T+1}^{S} (M_{s,1}(I(B)) + D_{s,1}(I(B)) + O_{s,1}) = \sum\nolimits_{t=1}^{T} F_{t,1} + \sum\nolimits_{s=T+1}^{S} I_{s,1}(B) + \sum\nolimits_{l=1}^{L} B_{l,1} \\ &B_{l,1}, I_{s,1} \geq 0 \end{aligned} \tag{10}$$

According to the envelope theorem, we can obtain $\partial W_1/\partial I_{s,1} = 0$, and $\partial M_{s,1}/\partial I_{s,1} + \partial D_{s,1}/\partial I_{s,1} = y/q$. Based on the theorem, the left and right sides of the equation synchronously multiply $\partial I_{s,1}/\partial B_{l,1} = q\cdot(\partial P_1/\partial B_{l,1})$. The expression of the marginal effect of debt on maintenance expenditure $\partial M_{s,1}/\partial B_{l,1}$ is as follows in Eq. (11).

$$\partial M_{s,1}/\partial B_{l,1} = (\partial M_{s,1}/\partial I_{s,1})\cdot(\partial I_{s,1}/\partial B_{l,1}) = (y/q)\cdot(\partial I_{s,1}/\partial B_{l,1}) - (1 + r_1)^l \tag{11}$$

where $(1 + r_1)^l$ indicates the compound rate in period l, and $\partial I_{s,1}/\partial B_{l,1}$ is the marginal effect of debts on toll revenue. To analyze the marginal effect of debt scale on maintenance, the following three scenarios are discussed.

When $\partial I_{s,1}/\partial B_{l,1} < (q/y)\cdot(1 + r_1)^l$and assuming q is close to y, we have the relation of $e^1{}_{I,B} < (D_{s,1}/I_{s,1})$, that is, the elasticity of debt to toll revenue showing the degree to which a 1% change in debt causes a change in toll revenue is less than the ratio of debt repayment to toll revenue. Hence, the marginal effect of debt on maintenance is less than zero., and the change of debt scale decreases maintenance expenditure, which indicates the substitution effect. Otherwise, if there is a larger gap between the marginal effect of debt on toll revenue and compound interest, the substitution effect of $B_{l,1}$ on $M_{s,1}$ will be stronger.

When $\partial I_{s,1}/\partial B_{l,1} > (q/y)\cdot(1+r_1)^l$and assuming q is close to y, we have the relation of $e^1{}_{I,B} > (D_{s,1}/I_{s,1})$,[3] that is, the elasticity of debt to toll revenue showing the degree to which a 1% change in debt causes a change in toll revenue is larger than the ratio of debt repayment to toll revenue. Hence, the marginal effect of debt on maintenance is greater than zero $\partial M_{s,1}/\partial B_{l,1} > 0$, and the change of debt scale increases maintenance expenditure, which indicates the complementary effect. Otherwise, if there is a larger gap between the marginal effect of debt on toll revenue and compound interest, the complementary effect of $B_{l,1}$ on. will be stronger.

When $\partial I_{s,1}/\partial B_{l,1} = (q/y)\cdot(1+r_1)^l$ and assuming q is close to y, we have the relation of $e^1{}_{I,B} = (D_{s,1}/I_{s,1})$, that is, the elasticity of debt to toll revenue showing the degree to which a 1% change in debt causes a change in toll revenue is equal to the ratio of debt repayment to toll revenue. Hence, when $\partial M_{s,1}/\partial B_{l,1} = 0$, a change of debt scale does not affect the maintenance expenditure, which contradicts the theoretical assumptions. Obviously, the conclusion is not valid.

In summary, the two scenarios of substitution effect and complementary effect meet the assumptions. To further measure whether the cost of debt is related to the size of the effect of $\partial M_{s,1}/\partial B_{l,1}$, we need to explore how r_1 affects $\partial M_{s,1}/\partial B_{l,1}$. From Eq. (12), we find that the change shows an opposite trend, and is less than 0. This shows that even if the marginal effect of debt on maintenance expenditure is either a complementary effect or a substitution effect, as long as r_1 increases in the first stage, the substitution effect becomes larger and the complementary effect smaller.

$$(\partial M_{s,1}/\partial B_{l,1})/\partial r_1 = -l(1+r_1)^{l-1} < 0 \tag{12}$$

H1. In the "spend-and-debt" financing model and the unconstrained debt financing model, when the cost of debt repayment is heavy and even snowballing in the first stage, the marginal effect of debt on maintenance expenditure is either a complementary effect or a substitution effect, with the substitution effect becoming larger and the complementary effect becoming smaller.

3.2.2. Second stage of social welfare maximization

Compared with the first stage, the second stage of toll road is implemented with a combination of tollway bonds and a maintenance management. The issuance of tollway bonds can prevent the phenomenon of borrowing new debt to repay old debt, and deciding how many roads to build based on how much debt is issued can be regarded as a "debt-and-spend" type. Therefore, the new construction scale $G_{t,2}$ is a function of $B_{t,2}$ as $G_{t,2}(B)$ in the second stage. In the first stage, $M_{s,1}$ is determined by the size of $I_{s,1}$. The higher the P_1, the more $I_{s,1}$, and the corresponding expenditure that can be invested in maintenance increases. Compared with the first stage, $M_{s,2}$ is no longer a function of $I_{s,2}$ in the second stage, but has become a function of construction scale $G_{t,2}$, $M_{s,2}(G)$. The reason for the change is based on the toll goals of different stages. The charging basis for the first stage is to pay off the loan and debt, and the maintenance expenditure is not an imperative mission for government-operated toll roads. Since this stage begins to pay attention to maintenance management, the basis for charging is not only to pay off debt, but also to provide better services and quality, and to ensure no congestion and safety on the road. Hence, the variables of P_2 extend from $B_{t,2}$ to $M_{s,2}$, $P_2(B, M)$. The variables in this stage $B_{t,2}$ are significantly different from those in the first stage $B_{l,1}$, which means that the tollway bonds instead of financing debts for previous private sectors can avoid the phenomenon of borrowing new debt to repay old debt, and determine how many roads to build is determined by the amount of debt issued. Therefore, the utility function of road users can be expressed by $U_2(q) = \int_0^y P_2(B, M(G)) + T(q)dq$. Meanwhile, the vehicle toll revenue of the second stage can be defined as

$$\sum\nolimits_{s=T+1}^{S} I_{s,2}(B, G(B)) = \sum\nolimits_{s=T+1}^{S} q \times P_2(B, M(G)) \tag{13}$$

In the second stage, there is no borrowing new debt to repay old debt, and $D_{s,2}$ is determined not only directly by $G_{t,2}$, but also indirectly by $B_{t,2}$. Thus, $(\partial D_{s,2}/\partial G_{t,2})\cdot(\partial G_{t,2}/\partial B_{t,2}) = (1+r_2)^t$, which highlights repayment of debt for construction. The marginal impact of the second stage is different from that of the first stage in interest rates ($r_2 < r_1$) and period ($t < l$). Thus, the total expenditures of the second stage in the operating period have changed. The total expenditures can be set as follows:

$$\sum\nolimits_{s=T+1}^{S} E_{s,2}(B, G(B)) = \sum\nolimits_{s=T+1}^{S} (M_{s,2}(G(B)) + D_{s,2}(G(B)) + O_{s,2}) \tag{14}$$

Based on the above Eq. (14), the total social welfare of toll roads W_2 has changed in Eq. (15).

$$W_2(B, G(B)) = \sum\nolimits_{s=T+1}^{S} \left(\int_0^y P_2(B, M(G(B))) + T(q)dq - (M_{s,2}(G(B)) + D_{s,2}(G(B)) + O_{s,2}) \right) \tag{15}$$

In Eq. (16), it is the first-order partial derivative of the W_2 with respect to the variables $B_{t,2}$ and $G_{t,2}$.

$$\begin{aligned} \partial W_2/\partial B_{t,2} &= y\cdot(\partial P_2/\partial B_{t,2}) - (\partial M_{s,2}/\partial G_{t,2})\cdot(\partial G_{t,2}/\partial B_{t,2}) - (1+r_2)^t \\ \partial W_2/\partial G_{t,2} &= y\cdot(\partial P_2/\partial M_{s,2})\cdot(\partial M_{s,2}/\partial G_{t,2}) - (\partial M_{s,2}/\partial G_{t,2}) - (\partial D_{s,2}/\partial G_{t,2}) \end{aligned} \tag{16}$$

Known $\sum_{t=1}^{T}(1+r_2)^t B_{t,2} = \sum_{s=T+1}^{S} D_{s,2}$, the budget constraint is also the identity of income and expenditure in Eq. (2). Thus, Eq. (17) is the welfare maximization and constraint conditions of the second stage.

[3] Given that the elasticity of debt to toll revenue is $e^1{}_{I,B} = (B_{l,1}/\partial I_{s,1})\cdot(\partial I_{s,1}/\partial B_{l,1})$, multiply the left and right sides of the $\partial I_{s,1}/\partial B_{l,1} > (q/y)\cdot(1+r_1)^l$ by the $B_{l,1}/I_{s,1}$ to obtain $e^1{}_{I,B} > (q/y)\cdot(D_{s,1}/I_{s,1})$. When q is close to y, there is $e^1{}_{I,B} > (D_{s,1}/I_{s,1})$.

$$Max \sum_{i=1}^{n} W_2(B, G(B))$$
$$s.\ t.\ \sum_{s=T+1}^{S} I_{s,2}(B, M(G)) + \sum_{t=1}^{T} F_{t,2} + B_{t,2} = \sum_{t=1}^{T} G_{t,2}(B) + \sum_{s=T+1}^{S} (M_s(G(B)) + D_{s,2}(G(B)) + O_{s,2})$$
$$B_{t,2}, G_{t,2} \geq 0 \tag{17}$$

As mentioned, $G_{t,2}$ is a function of $B_{t,2}$. According to the envelope theorem, we have $\partial W_2/\partial G_{t,2} = 0$, and can be obtained $y \cdot (\partial P_2/\partial M_{s,2}) \cdot (\partial M_{s,2}/\partial G_{t,2}) = \partial M_{s,2}/\partial G_{t,2} + \partial D_{s,2}/\partial G_{t,2}$. Refer to Appendix 1 for details of Eq. (18).

$$\partial M_{s,2}/\partial B_{t,2} = (\partial M_{s,2}/\partial G_{t,2}) \cdot (\partial G_{t,2}/\partial B_{t,2}) = (y/q) \cdot (\partial I_{s,2}/\partial B_{t,2}) - (1 + r_2)^t \tag{18}$$

where $(1 + r_2)^t$ indicates the compound rate in period t. Divide both sides of Eq. (18) by $\partial G_{t,2}/\partial B_{t,2}$, and put in the relation $y \cdot (\partial P_2/\partial M_{s,2}) \cdot (\partial M_{s,2}/\partial G_{t,2}) = \partial M_{s,2}/\partial G_{t,2} + \partial D_{s,2}/\partial G_{t,2}$to obtain $\partial G_{t,2}/\partial B_{t,2} = 1$. Then, we have Eq. (19).

$$\partial M_{s,2}/\partial B_{t,2} = \partial M_{s,2}/\partial G_{t,2} = (y/q) \cdot (\partial I_{s,2}/\partial B_{t,2}) - (1 + r_2)^t \tag{19}$$

The marginal effect of debt scale on conservation $\partial M_{s,2}/\partial B_{t,2}$ equals the marginal effect of construction scale on maintenance $\partial M_{s,2}/\partial G_{t,2}$. It is easy to observe that $G_{t,2}$ becomes an intermediate variable between both $M_{s,2}$ and $B_{t,2}$. To a certain extent, $\partial M_{s,2}/\partial G_{t,2}$ can reflect the need for maintenance meeting the depreciation of infrastructure. With the expansion of road construction, the responsibility for maintenance expenditure increases.

To analyze the marginal effect of debt scale on maintenance, the following three scenarios are discussed.

When $\partial I_{s,2}/\partial B_{t,2} < (1 + r_2)^t$ and assuming q is close to y, we have the relation of $e^2{}_{I,B} < (D_{s,2}/I_{s,2})$, that is, the elasticity of debt to toll revenue showing the degree to which a 1% change in debt causes a change in toll revenue is less than the ratio of debt repayment to toll revenue. Thus, we have $\partial M_{s,2}/\partial B_{t,2} = \partial M_{s,2}/\partial G_{t,2} < 0$. There is a substitution effect between the debt scale and maintenance expenditure, that as the scale of $B_{t,2}$ increases, necessary and preventive $M_{s,2}$ decreases. Otherwise, if there is a larger gap between $\partial I_{s,2}/\partial B_{t,2}$ and $(1 + r_2)^t$, the stronger the substitution effect of $B_{t,2}$ on $M_{s,2}$.

When $\partial I_{s,2}/\partial B_{t,2} > (q/y)(1 + r_2)^t$ and assuming q is close to y, we have the relation of $e^2{}_{I,B} > (D_{s,2}/I_{s,2})$,[4] that is, the elasticity of debt to toll revenue showing the degree to which a 1% change in debt causes a change in toll revenue is larger than the ratio of debt repayment to toll revenue. Thus, we have $\partial M_{s,2}/\partial B_{t,2} = \partial M_{s,2}/\partial G_{t,2} > 0$, and there is a complementary effect between the debt scale and maintenance expenditure, that as the scale of $B_{t,2}$ increases, necessary and preventive $M_{s,2}$ increases. Otherwise, if there is a larger gap between $\partial I_{s,2}/\partial B_{t,2}$ and $(1 + r_2)^t$, the stronger the complementary effect of $B_{t,2}$ on $M_{s,2}$.

When $\partial I_{s,2}/\partial B_{t,2} = (1 + r_2)^t$and assuming $q$is close to y, we have the relation of $e^2{}_{I,B} = (D_{s,2}/I_{s,2})$, that is, the elasticity of debt to toll revenue showing the degree to which a 1% change in debt causes a change in toll revenue is equal to the ratio of debt repayment to toll revenue. Thus, we have $\partial M_{s,2}/\partial B_{t,2} = \partial M_{s,2}/\partial G_{t,2} = 0$, and the change of debt scale does not affect the maintenance expenditure, which is regarded as contradictory to theoretical assumptions. Obviously, this conclusion is not valid.

To sum up, the two scenarios of substitution effect and complementary effect meet the assumptions. As governments issue tollway bonds to raise funds for road construction at this stage, the burden of debt is reduced to a certain extent, and the difference from the first stage is r_1. To further explore how r_2 affects $\partial M_{s,2}/\partial B_{t,2}$, with a decrease of r_2, the first derivative of r_2 can be calculated in Eq. (20).

$$(\partial M_{s,2}/\partial B_{t,2})/\partial r_2 = (\partial M_{s,2}/\partial G_{t,2})/\partial r_2 = -t(1 + r_2)^{t-1} < 0 \tag{20}$$

From Eq. (20), we find that the change rate is less than 0. There is a decrease from r_1 to r_2 ($\triangle r_2 < 0$), the loan cycle is shortened from l to t ($\triangle t < 0$), and borrowing new debt to repay old debt does not occur during the operating period. This result illustrates that whether it is the substitution effect or the complementary effect, as r_2 decreases in this stage, the marginal effect of the tollway bonds on maintenance increases, that is, narrows the substitution effect and enlarges the complementary effect, which benefits the degree of road maintenance. Therefore, this explains that effective control of debt costs not only can alleviate the substitution effect, but also can help improve the complementary effect.

H2. Under the "debt-and-spend" financing model and the constrained lending model, there is both a substitution effect and a complementary effect between tollway bonds and road maintenance. When the burden of debt repayment becomes controllable in the second stage, it narrows the substitution effect or enlarges the complementary effect, both of which would be beneficial for maintenance expenditure.

4. Empirical approach

4.1. Data

4.1.1. Data sources

The data come from the *Toll Roads Statistical Bulletin*, NBS, and the *Chinese Research Data Services Platform* (CNRDS) in China. The data of *Toll Roads Statistical Bulletin* are manually collected, and are cross-validated to ensure feasibility. Data acquisition sources are authoritative and decentralized, such as China's sub-stations, the local transportation department, the local government, the interpretation of the *Toll Roads Statistical Bulletin*, the China highway network, and other open government columns. Since the publication of the China *Toll Roads Statistical Bulletin* started in 2013, the available

[4] Given that the elasticity of debt to toll revenue is $e^2{}_{I,B} = (B_{t,2}/\partial I_{s,2}) \cdot (\partial I_{s,2}/\partial B_{t,2})$, multiply the left and right sides of the $\partial I_{s,2}/\partial B_{t,2} > (q/y)(1 + r_2)^t$ by the $B_{t,2}/I_{s,2}$ to obtain$e^2{}_{I,B} > (q/y) \cdot (D_{s,2}/I_{s,2})$. When q is close to y, there is $e^2{}_{I,B} > (D_{s,1}/I_{s,1})$.

data are relatively short. Few provinces issued and published data in 2013 and 2014, and there is a large volume of missing data.

The sample are provincial panel data from 2013 to 2019 in China, excluding Hainan and Tibet, because Hainan's toll is different to others, and Tibet does not charge highway tolls, and neither of these two provinces provides statistical bulletins on toll roads.[5] Most provinces have both government-operated toll roads and commercial toll roads. However, some provinces have only government-operated toll roads (Gansu and Xinjiang) or commercial toll roads (Tianjin and Chongqing), and one province even has data for 2016 in which all government-operated toll roads were converted to commercial toll roads (Liaoning). In addition, there are a lot of missing data in Heilongjiang Province, so the sample of government-operated toll roads only covers 25 provinces.

4.1.2. Variables and description

To control the mileage differences of regional toll roads, refer to the measure of maintenance cost in the research of López-Pita et al. (2008) and Rouse and Chiu (2009). In this study, the explained variable is maintenance expenditure per kilometer, which is the logarithm of the maintenance expenditure per kilometer of toll roads (log*AveMain*). Due to differences in geographical environment, economic development, and resource endowments among provinces, there is a huge difference in the mileage of toll roads. The greater the mileage, the larger the maintenance expenditure scale. Therefore, we can objectively use maintenance expenditure per kilometer to measure provincial differences. This study elects the total maintenance expenditure(log*MainEx*) and per capita maintenance expenditure (log*PerMain*) to strengthen the robustness analysis. In addition, for the proportion of maintenance expenditure to total expenditure (*MainRatio*), we refer to Chitra (2003) to measure the attention paid to maintenance expenditures.

The core explanatory variable is the time when the local tollway bonds is issued (*Treat*×*Post*), which is the dummy variable. If the tollway bonds were issued by a province that is in the treatment group (*Treat*), it is assigned a value of 1, and otherwise 0. If the time (*Post*) is the issuance of the tollway bonds, the dummy variable will take 1, and otherwise 0. In addition, the explanatory variable includes the proportion of debt repayment to total expenditure (*DebtRatio*). Control variables are mainly selected according to economic, social, and natural factors, among others. The economic development level of each province is based on the ratio of gross domestic product of the transportation, storage, and postal industry to the total of gross domestic product (*Trafficgdp*), the logarithmic of highway passenger flow (log*Freight*), and the logarithmic of highway freight flow (log*Passenger*), and the degree of openness (*Open*). Social factors include population density, which equals the total population divided by the administrative area (*Popden*). Natural factors include the average altitude (*Altitude*) and area (*Area*). Others include the proportion of expressways in highways (*Highprop*), the number of toll stations (*Station*), the mileage of toll roads (log*Mileage*), and the proportion of the accumulated capital of bank loan capital (*Loanratio*). Moreover, there are two adjustment variables, active maintenance (*nogap*) and passive maintenance (log*Acinvest*). For the statistical description of variables, see Table B1 in Appendix 2.

4.2. Empirical estimation

In 2017, China began to issue tollway bonds in the field of government-operated toll roads, and gradually expanded the scope of the trial. Tollway bonds will become the only channel for the government to solve the problem of debt financing of the construction of government-operated toll roads. Although the policy was issued in 2017, the implementation time of each province is inconsistent. Therefore, we select the time-varying difference-in-differences approach to estimate the effect of the policy. According to the implementation location and time of the policy, 23 provinces that have issued tollway bonds can be set as the treatment group, and 6 provinces that have not issued tollway bonds are set as the control group. For the specific time of special bonds for toll roads, refer to Table B2 in Appendix 2. The model is

$$M_{it} = \alpha_0 + \alpha_1 Treat_{it} \times Post_{it} + \mathbf{X}'_{it}\boldsymbol{\beta} + \varphi\mu_i \times t + \mu_i + \tau_t + \varepsilon_{it} \tag{21}$$

Here, M_{it} refers to the maintenance expenditure of toll roads in i ($i = \{1, .,29\}$) provinces at t ($t = \{2013, .,2019\}$) year, α_0 is the constant, μ_i and τ_t represent the fixed effects of province and year, and ε_{it} represents the error. The interaction of $Treat_{it} \times Post_{it}$ is a dummy variable for i provinces to issue tollway bonds in t year. A positive coefficient α_1 indicates that the policy of tollway bonds has a complementary effect on the maintenance of the government-operated toll roads; while a negative coefficient α_1 reflects the substitution effect of tollway bonds on government-operated toll roads. $\mathbf{X}_{it}$ represents a $k \times 1$ vector of control variables in i provinces in t year, where $\boldsymbol{\beta}$ represents the coefficient of $k \times 1$ vector of control variables. It is worth mentioning that the model adds interaction term for province trends, i.e., year trends at the provincial level ($\mu_i \times t$), indicating a province-year linear time trend, to control for the year trends in different provinces. At the same time, this model also controls the fixed effects of provinces (μ_i) and the fixed effects of years (τ_t).

[5] According to the *Regulations on the Administration of the Collection of Motor Vehicle Passage Surcharges in the Hainan Special Economic Zone*, the Hainan levies gasoline passing surcharges, which are levied outside the gasoline supply chain. Hainan Province began to levy fuel taxes in 1994, and implemented the "four fees in one" method of collecting road maintenance fees, tolls, bridge fees, and transportation management fees for diesel vehicles. There are no toll roads in Tibet.

Table 1
Effects of tollway bond financing on maintenance.

Variables	(1)	(2)	(3)	(4)	(5)
	Government-operated toll roads: logAveMain				
Treat × Post	0.2816**	0.3129***	0.2402**	0.0791	0.3021**
	(2.34)	(3.16)	(2.60)	(0.78)	(2.23)
Controls	No	Yes	Yes	Yes	Yes
Province FE	No	No	Yes	Yes	Yes
Year FE	No	No	No	Yes	Yes
Province trend	No	No	No	No	Yes
Observations	143	143	143	143	143
R-squared	0.0904	0.4181	0.4557	0.5132	0.7129

Notes: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$; robust in brackets.

5. Empirical results

5.1. Effects of tollway bond financing on maintenance

Table 1 shows the results of the effects of tollway bond financing on maintenance of time-varying DID. The explained variable, maintenance expenditure, adopts the logarithmic form of the average maintenance expenditure per kilometer (log*AveMain*), reflecting the effect of the tollway bond policy that was gradually implemented in 2017 on the maintenance expenditure of government-operated toll roads. Column (1) in Table 1 presents results for a model that does not include control variables and fixed effect (FE); column (2) shows results that include control variables; column (3) shows results that includes control variables and a province FE; column (4) shows results that include control variables, a province FE, and a year FE; column (5) shows results for a model that includes control variables, a province FE, a year FE, and province trend. From column (1), the direction of the coefficient is 0.2816 and significant at the level of 5%. The coefficient of columns (1), (2), (3), and (5) are significantly positive and the coefficient difference is small. Since the interaction of province trend is not considered, the direction of the regression result in column (4) is 0.0794 and not significant. To increase the robustness of the regression results, this study increases the province-year linear trend in column (5), and captures the trends of different provinces changing with the year; the regression shows that the results are still significant at the 5% level, with an impact coefficient of 0.3021. Therefore, we conclude from the results of Table 1 that the issuance of tollway bonds has significantly increased the level of maintenance expenditure in China, and the issuance of tollway bonds has had a significant positive effect on maintenance expenditure.

5.2. Dynamic effects

Drawing on Beck et al. (2010) and Wing et al. (2018), we divide the policy into a phase-in effect, immediate effect, and anticipated effect by event study. We analyze the dynamic impact of highway special bonds on the degree of road maintenance into different stages. According to the characteristics of the data structure, this study selects the first 5 years of the event and the 2 years after the event for analysis. The model is set as follows:

$$M_{it} = \beta_0 + \sum_{s=1,s\neq t}^{S} \gamma_s Treat_{it-s} \times Post_{it-s} + \delta Treat_{it} \times Post_{it} + \sum_{m=1,m\neq t}^{M} \phi_m Treat_{it+m} \times Post_{it+m} + \mu_i + \varepsilon_{it} \tag{22}$$

where, the interaction term of $Treat_{it-s} \times Post_{it-s}$ is 1 when $t-s$ of province i is s years before the policy of tollway bonds, and otherwise 0, where $s = \{1, 2, 3, 4, 5\}$. $Treat_{it+m} \times Post_{it+m}$ is 1 when $t+m$ of province i is m years after the policy of tollway bonds, and otherwise 0, where $m = \{1, 2\}$. The abovementioned three effects can capture and reflect the year effect to a certain extent. γ_s describes the phase-in effect of the policy, δ describes the immediate effect of the policy, and ϕ_m describes the anticipated effect of the policy. If the coefficient of δ is positive, $\phi_m < 0$ means that the anticipated effect weakens over time, and $\phi_m > 0$means that it increases over time (Wing et al., 2018).

Fig. 2 shows the dynamic regression results of tollway bonds on maintenance expenditure of government-operated toll roads and shows a parallel trend test of time-varying difference-in-differences. In order to be consistent with Chen (2017), this study select the year before the policy as the base period. Before the policy, the previous debt financing model had a small positive effect on road maintenance, but it was not significant. With the development of tollway bonds, not only is the anticipated effect significantly positive, but the coefficient of anticipated effect gradually increases over time and is much higher than the phase-in effect. The parallel trends before and after the policy are consistent and appear to be on an upward trend. Therefore, Fig. 2 satisfies the parallel trend hypothesis, and shows that tollway bonds have improved the degree of road maintenance. After the conversion of the debt financing source, the local debt structure was effectively regulated, and tollway bonds were used for government-operated toll roads. As a result, the government has more budget for road maintenance, and road maintenance investment gradually has been paid increasingly large attention.

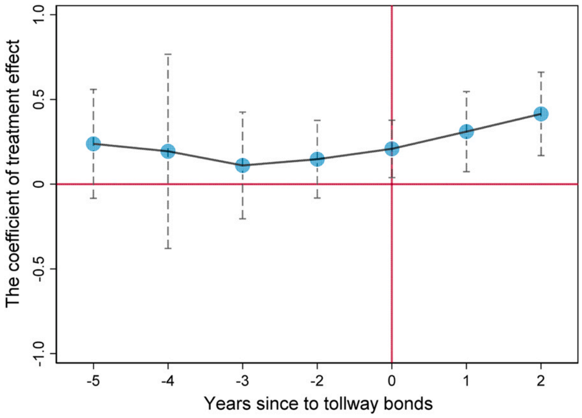

Fig. 2. The dynamic effects of tollway bonds on maintenance expenditure from 2013 to 2019. Notes: The blue dashed line is a 95% confidence interval, and the gray line represents a dynamic coefficient for the treatment effect.

5.3. Robustness checks

To further validate the robustness of the results in Table 1, this study replaces the explained variable, which is the total scale of maintenance expenditure (log*MainEx*), with the per capita maintenance expenditure (log*PerMain*), which further supports the regression results in Table 1. The reason for this selection is that log*MainEx* can measure the total local government investment in maintenance in government-operated toll roads, while per capita conservation expenditure can capture the population effect on maintenance from the demand-side perspective.

Table 2, column (1) presents the regression result of log*MainEx*, and column (2) presents that of log*PerMain*. The coefficients are 0.3112 and 0.3117, respectively, and both are significant at the 5% level. Models (1) and (2) increase the variables of the mileage of toll roads (*Mileage*) in the control variables compared to Table 1 because the mileage of toll roads greatly determines the scale of maintenance expenditure. Therefore, the results of Table 2 further support the conclusion of the benchmark regression. Tollway bonds standardize the debt-financing scale, strictly prevent debts risks, and reduce the debt burden. To a certain extent, tollway bonds are conducive to improving the maintenance of government-operated toll roads.

5.4. Effects of randomizing policy time

The tollway bond program has been implemented in all regions since 2017. To further test whether it is affected by other policies or shocks, a placebo test is needed to check the previous results. Drawing on Behr and Sonnekalb (2012) and Chen (2017) for the placebo test, the policy issuance time can be advanced by 1, 2, and 3 years to observe whether the results would still be affected by the treatment effects by fictionalizing the issuance time of the tollway bonds. Table 3 presents the results of the time of tollways bonds advanced by 1, 2, and 3 years. The results show that whether the policy timing is advanced by any number of years, the estimated coefficients of fictitious policy variables are not significant, and thus, interference from other policies and a macro shock can be excluded. The result further proves that the financing mode of tollway bonds has promoted road maintenance expenditure.

To eliminate the interference of the error term or unobservable variables in the toll road bond pilot, this study estimates the impact of road special bonds on maintenance expenditure by establishing a random sample. We randomly select different provinces as the treatment group and repeat the regression 500 times (Cai et al., 2016). Fig. 3 reports the distribution of maintenance expenditures for the randomly selected treatment group. We find that the coefficient values of the fictitious policy samples on the maintenance expenditure are clustered around 0, which is completely independent of the distribution compared with the initial

Table 2
Regression results of the robustness analysis.

Variables	(1) logMainEx	(2) logPerMain
Treat × Post	0.3112**	0.3117**
	(2.18)	(2.19)
Controls	Yes	Yes
Province FE	Yes	Yes
Year FE	Yes	Yes
Province trend	Yes	Yes
Observations	143	143
R-squared	0.654	0.647

Notes: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$; robust in brackets.

Table 3
Effects of randomizing policy time.

Variables	(1)	(2)	(3)
	Government-operated toll roads: logAveMain		
Treat × F_1Post	-0.0625 (−0.30)		
Treat × F_2Post		0.1714 (0.84)	
Treat × F_3Post			-0.3894 (−1.36)
Controls	Yes	Yes	Yes
Province FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Province trend	Yes	Yes	Yes
Observations	143	143	143
R-squared	0.700	0.703	0.708

Notes: *** p < 0.01, ** p < 0.05, and * p < 0.1; robust in brackets; $Treat_{it} \times F_1Post_{it}$ denotes the time of tollways bonds advanced by 1 year (F_1Post_{it}), $Treat_{it} \times F_2Post_{it}$ represents the time of tollways bonds advanced by 2 years (F_2Post_{it}), and $Treat_{it} \times F_3Post_{it}$ designates the time of tollways bonds advanced by 3 years (F_3Post_{it}).

estimated coefficient of 0.3021. Therefore, other unobservable factors are less likely to interfere with the benchmark estimation result.

5.5. Spillover effects and heterogeneity

5.5.1. Spillover effects

As mentioned in the introduction, toll roads are divided into two types in China, namely government-operated toll roads (denoted by the symbol g) and commercial toll roads (denoted by the symbol c). The policy implementation of tollway bonds includes only government-operated toll roads. Since there is no complete division between commercial and government-operated toll roads, the toll road network is large, connected, and interlaced. Network effects and spatial spillovers are inherent effects of transport infrastructure (Condeço-Melhorado et al., 2014). Therefore, it is impossible to visually distinguish between commercial toll roads and government-operated toll roads. However, the difference between them can also be determined by toll bills and institutions or entities. For example, there are two types of toll roads on the Chengdu to Mianyang Expressway in China. The section of the Chengdu-Mianyang Expressway comprises commercial toll roads, and the section of the Mianyang Ring Expressway constitutes government-operated toll roads. For details, see Fig. B1 in Appendix 2.

On the one hand, once the new roads are constructed through the issuance of tollway bonds, the traffic network of toll roads will be gradually improved, the accessibility in the transportation network will also increase, and the continuous play of network effects will also promote the flow of factors between regions, reduce transportation costs, and consolidate the structure of the highway infrastructure network. Hence, what we call "network effects." On the other hand, when the tollway bond issue ($B^g_{t,2}\uparrow$), the construction quantity of the government toll road increases ($G^g_{t,2}\uparrow$), resulting in the commercial toll road being able to obtain more traffic flows ($q^c_{s,2}\uparrow$), more revenue is generated ($I^c_{s,2}\uparrow = \sum_{s=T+1}^{S} q^c_{s,2}\uparrow \times P_2$), which increases the maintenance costs of commercial toll roads ($E^c_{s,2}\uparrow = M^c_{s,2}\uparrow + D^c_{s,2} + O^c_{s,2}$). Among them, the cost of travel time for road users has also increased ($T^c_{s,2}(q)\uparrow$), and there is a further urgent need for maintenance ($M^c_{s,2}\uparrow$) to improve road conditions. If $D^c_{s,2}$and $O^c_{s,2}$ are unchanged of commercial toll road, the proportion

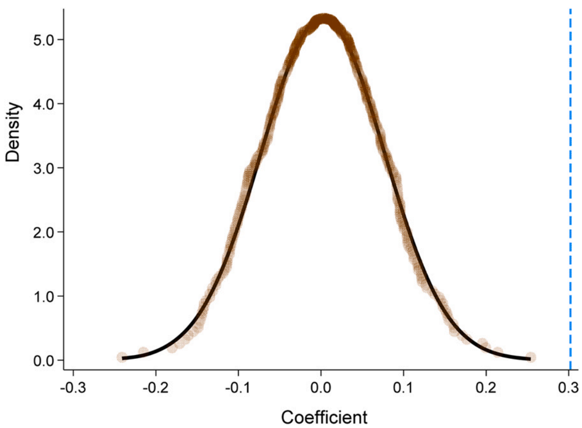

Fig. 3. Kernel density of maintenance expenditure. Notes: The blue dashed line is the basic regression coefficient of 0.3021.

Table 4
Spillover effects of commercial toll roads.

Variables	(1)	(2)	(3)	(4)	(5)
	Commercial toll roads: logAveMain				
Treat × Post	0.3671***	0.4296***	0.2339***	0.1128	0.2475 * (1.83)
	(3.56)	(4.13)	(2.90)	(1.03)	
Controls	No	Yes	Yes	Yes	Yes
Province FE	No	No	Yes	Yes	Yes
Year FE	No	No	No	Yes	Yes
Province trend	No	No	No	No	Yes
Observations	150	150	150	150	150
R-squared	0.171	0.270	0.344	0.426	0.761

Notes: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$; robust in brackets; the sample data of the commercial toll roads differ from the government-operated toll roads.

of expenditure on maintenance ($(M^c_{s,2}/E^c_{s,2})\uparrow$) will increase as budgetary constraints increase ($R^c_{s,2} \uparrow = I^c_{s,2} - E^c_{s,2} \geq 0$). Hence, what we call "spillover effects." Therefore, both in terms of spatial geographic linkages and increasing traffic flows, it can be illustrated that government-operated tollway bonds have network effects and spillover effects (Condeço-Melhorado et al., 2014) on commercial toll roads.

Considering that the sample data of commercial toll roads is independent of government-operated toll roads, the explanatory variable (log*AveMain*) refers to the maintenance expenditure of the commercial toll road. Table 4 shows the regression results of the spillover effect of commercial toll roads. Tollway bonds have a positive impact on commercial toll roads of 0.2475 at the 10% statistical significance level, which is less than the policy effect of government-operated toll roads. This result shows that the policy has a significant spillover effect on commercial toll roads, and the impact is relatively obvious. Furthermore, toll bonds have not only significantly improved government-operated toll roads but also enhanced the maintenance of the surrounding commercial toll roads.

5.5.2. Heterogeneity

According to grade types on toll road, government-operated toll roads can be divided into expressways, first-grade highways, second-grade highways (Chen et al., 2016), bridges, and tunnels. In 2009, the State Council of China issued a notice on the *Gradually and Orderly Cancellation of Government Loan Repayment Secondary Road Tolls Implementation Plan*. Under this scheme, different regions will gradually cancel government loan repayment secondary road tolls. Judging from the data in the statistical bulletin of the toll roads of each province, the data collection of the secondary roads during the sample period has stopped. Therefore, Table 5 reports only the other four types of regression results. The results show that only the results for expressways are positively significant, which is in line with the regulations on the use of tollway bond capital in the *Administrative Measures for Special Bonds for Local Government Toll Roads* (Trial) issued in 2017, that is, priority for the construction of national highway projects. In addition, the results of first-grade highways and bridges are negative but not significant, which reflects that the issuance of highway bonds has a heterogeneous effect on toll roads of different grades and has less impact on types of toll roads other than expressways. Although the regression results of the tunnels are significantly positive at the 1% level, the findings are not robust owing to the small sample size, and thus, this study does not refer to the regression results of the tunnels. The policy impact of tollway bonds is mainly manifested in the type of expressways. According to data from China's *Toll Roads Statistical Bulletin*, the ratio of expressway mileage to government-operated toll roads mileage in 2020 was as high as 79.1%, which is realistic. Moreover, the regression results of expressways in Table 5 further support the conclusions.

Table 5
Heterogeneity effects of government-operated toll roads.

Variables	(1)	(2)	(3)	(4)
	Government-operated toll roads: logAveMain			
	Expressway	First-grade highway	Bridges	Tunnels
Treat × Post	0.3117**	-0.6050	-1.3922	13.1738***
	(2.10)	(−0.73)	(−0.91)	(77.15)
Controls	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Province trend	Yes	Yes	Yes	Yes
Observations	135	85	40	20
R-squared	0.706	0.419	0.680	1.000

Notes: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$; robust in brackets; the table does not show the results of secondary toll roads, because the sample size is too small, and toll rights on secondary toll roads were gradually canceled during the sample period, resulting in the loss of data and cliffs.

5.6. Active maintenance and passive maintenance

As the financing model of tollway bonds reduces the repayment interest rate, the burden of debt repayment is reduced. The issuance of tollway bonds leads to a reduction in debt costs. The empirical analysis in this study up to now suggests that reducing debt costs can effectively promote increased road maintenance expenditure. Combined with the two-stage theoretical model, the influence path and adjustment effect of tollway bonds on maintenance expenditure are mainly explained from the following two perspectives: active and passive maintenance. In the mechanism, active maintenance and passive maintenance are listed from empirical data for comparison at different stages, active maintenance is related to the first stage of the theoretical model, $\partial M_{s,1}^g/\partial B_{l,1}^g = (\partial M_{s,1}^g/\partial I_{s,1}^g)\cdot(\partial I_{s,1}^g/\partial B_{l,1}^g)$, see Eq. (11); passive maintenance is related to the second stage of the theoretical model, $\partial M_{s,2}^g/\partial B_{t,2}^g = \partial M_{s,2}^g/\partial G_{t,2}^g$, see Eq. (19).

The public good nature of toll roads assigns a responsibility on governments to provide sound and efficient infrastructure (Arif et al., 2021). "Active maintenance" is defined from the perspective of fiscal gap in vehicle tolls, where the toll revenue and expenditure gap (*nogap*) for government-operated toll roads is the use of toll revenue (I_s^g) minus the total expenditure (E_s^g). Variable *nogap* is a dummy variable that takes the value 1 to indicate a surplus in revenue and expenditure, and the value 0 to indicate that there is a gap in revenue and expenditure. When there is no such gap (if $R_s^g = I_s^g - E_s^g \geq 0$, $nogap_s^g = 1$), the local government has sufficient budget capital and ability to increase investment in maintenance. When there is a revenue and expenditure gap (if $R_s^g = I_s^g - E_s^g < 0$, $nogap_s^g = 0$), local governments cannot meet maintenance investment through policies and budgets. Among them, the revenue (I_s^g) from the vehicle toll of the government-operated toll road refers to the vehicle toll fee used to repay the construction debt of the government-operated toll road and so on. Government-operated toll road vehicle toll expenses (E_s^g) include road repayment (D_s^g), maintenance (M_s^g), and other expenses (O_s^g). Therefore, the greater the gap between revenue and expenditure ($nogap_s^g = 0$), the tighter the expenditure constraints on maintenance; the more surplus of revenue and expenditure ($nogap_s^g = 1$), and the more secure the source of funds for expenditure including maintenance.

"Passive maintenance" is defined from the perspective of fiscal expenditure responsibility. The variable log*Acinvest* reflects the construction scale of toll roads, that is, the capital stock of highways, including not only the capital already built but also the new capital, which mirrors the necessary maintenance through the cumulative construction scale (G_t^g) to reflect the expenditure responsibilities of local governments on road maintenance. Since tollway bonds are based on the principle of "debt-and-spend," the scale of construction is determined by the bonds issued, and the scale of construction is regulated and restricted by the scale of tollway bonds. Once the construction scale is controlled and regulated, would the local government reduce the maintenance of toll roads?

From the perspectives of active maintenance and passive maintenance, Table 6 analyzes how the implementation of tollway bonds increases maintenance expenditure. Columns (1) and (3) present the regression results of the total scale of maintenance (log*MainEx*) and maintenance per mileage (log*AveMain*), as well as the regression results of active maintenance. This study attempts to analyze the impact of the government's revenue and expenditure scale on road maintenance expenditures through the issuance of road bonds by setting the interaction terms between the tollway bond policy effect (*Treat* × *Post*) and the fiscal revenue and expenditure gap (*nogap*). From the perspective of the coefficient, the policy of the tollway bonds has not significantly improved or narrowed the revenue and expenditure gap of local government, and there are insufficient funds to expand the budget for maintenance. Therefore, local governments cannot actively increase the levels of road maintenance by increasing the fiscal budget.

The total accumulated investment can reflect the scale of construction of toll roads in different provinces. Columns (2) and (4) of Table 6 present the regression result of passive maintenance. The main effect is significant at the 1% level, indicating that the policy

Table 6
The relationship of tollway bond issuance to active and passive maintenance.

Variables	(1)	(2)	(3)	(4)
	logAveMain		logMainEx	
Treat × Post	0.2695 * (1.85)	7.7353*** (4.27)	0.2122 (1.24)	8.1778*** (5.26)
nogap	-0.5680 (−1.40)		-0.5754 (−1.45)	
nogap × Treat × Post	0.3765 (0.72)		0.4667 (0.87)	
logAcinvest		-0.8176** (−2.17)		-0.8112 * (−1.89)
logAcinvest × Treat × Post		-0.4521*** (−4.04)		-0.4826*** (−4.98)
Controls	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Province trend	Yes	Yes	Yes	Yes
Observations	142	142	142	142
R-squared	0.738	0.796	0.645	0.717

Notes: *** p < 0.01, ** p < 0.05, and * p < 0.1; robust in brackets.

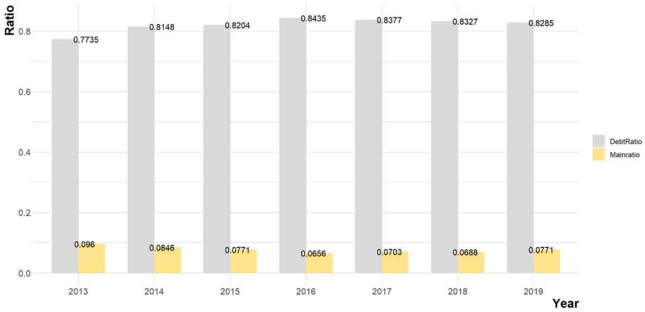

Fig. 4. The proportion of debt repayment and maintenance expenditure from 2013 to 2019 in China. Sources: Data are from the *Toll Roads Statistical Bulletin* in China.

of tollway bonds has significantly increased road maintenance expenditures compared to the difference between toll roads that have not issued road bonds. In addition, the coefficients of the interaction terms log*Acinvest* × *Treat* × *Post* in Columns (2) and (4) are − 0.4521 and − 0.4826, respectively, indicating that with the gradual increase of accumulated investment, the marginal effect of the implementation of tollway bonds on maintenance expenditure gradually weakens. Tollway bonds have availably met the local scale of important construction, which has, in turn, increased the corresponding expenditure responsibilities and further promoted investment in maintenance. In addition, the issuance of tollway bonds with affordable debt cost has not hindered economic growth, which is in line with the conclusion of Égert (2015).

5.7. Fact verification

The two conclusions in the optimal theoretical model of the second stage should be examined. Under different conditions, there is both a substitution effect and a complementary effect. Does the issuance of tollway bonds lessen the substitution effect or enlarge the complementary effect? This study further analyzes the abovementioned regression results and explains how tollway bonds make the increase in maintenance expenditure significant. Based on data from the *Toll Roads Statistical Bulletin* in China, Fig. 4 describes the proportion of debt repayment and maintenance expenditure of government-operated toll roads in China. In Fig. 4, debt repayment accounted for approximately 80% of the total expenditure, while maintenance expenditure accounted for less than 10%. From the Fig. 4, the proportion of debt repayment has declined since 2016. It is not difficult to discover that the ratio of debt repayment and the ratio of maintenance expenditure have a substitution relationship. Thus, it is necessary to explore the relationship between debt and maintenance in China to determine whether there is a substitution effect or a complementary effect and to investigate whether the policy effect of tollway bonds on maintenance is driven by a shrinking substitution effect or an expanding complementary effect.

Table 7 presents the results of the debt expenditure ratio and maintenance expenditure ratio, divided into two sample periods. Corresponding to the theoretical model, the first stage refers to the period before the issuance of tollway bonds, the second stage refers to the period after the issuance of tollway bonds, and the full sample includes both stages. Column (1) is the regression result of the sample period before the issuance of tollway bonds in each province, and the regression result is significant at the level of 1%, indicating that for every percentage point increase in the *DebtRatio*, the proportion of the *Mainratio* will be reduced by 0.3369. The first-stage sample results support the assumption in the first stage of the theoretical model, that is, under the "spend-and-debt" financing model, there is a substitution effect between unconstrained debt financing and maintenance expenditure, which supports hypothesis 1. The heavy debt levels are usually accompanied by high interest payments and fiscal austerity, which may cause changes in spending priorities and the need to reallocate budget shares (Mahdavi, 2004), as well as to enlarge the substitution effect between debt expenditure and maintenance expenditure; column (2) is the regression result of the sample period after the issuance of tollway bonds in each province, although the regression coefficient is 0.3083, it is not significant in statistical; column (3) is the return result

Table 7
The relationship of debt ratio to maintenance ratio in the two sample types.

Variables	(1) First stage (Post = 0)	(2) Second stage (Post = 1)	(3) Full sample (Post = 0,1)
	Mainratio		
DebtRatio	-0.3369***	0.3083	-0.3202***
	(−9.15)	(0.04)	(−3.05)
Controls	Yes	Yes	Yes
Province FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Province trend	Yes	Yes	Yes
Observations	87	50	137
R-squared	0.979	1.000	0.900

Notes: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$; robust in brackets.

of the full sample in each province, the impact coefficient at the 1% level is − 0.3202, reflecting that each percentage point increase in the *DebtRatio* would reduce the proportion of *Mainratio* by about 0.3202. For the full sample, the results show that the average coefficient of column (3) decreased from − 0.34 in the first stage to − 0.32, and there is still a substitution effect after the policy. The results also show that the coefficient of the overall mean has been reduced, and the substitution effect in the second stage has been alleviated.

Therefore, it can be seen from the above results that the effect of column (2), although positive, is not significant, and it is not possible to verify whether the sample period of column (2) is a substitution effect or a complementary effect. At the same time, this study focuses on testing the regression result coefficients of column (1) and column (3), and tests the influence coefficient of column (1) and column (3) based on the seemingly unrelated estimation (SUEST). Whether there is a difference in the influence coefficient between the groups, it is found that the coefficient difference of *DebtRatio* between the two groups in columns (1) and (3) is still not significant.

Through the time-varying difference-in-differences estimate of the effect of tollway bond financing on maintenance in this study, this study finds that the implementation of tollway bonds has effectively improved the scale of local maintenance expenditure. At the same time, various tests and analyses further proved that our conclusion is robust and effective. Finally, we use empirical results to explain whether the impact of bonds on public maintenance expenditure comes from the substitution effect or the complementary effect. This is because the tollway bond implementation reduces the substitution effect, which is consistent with the second-stage theoretical model. In the future, if the Chinese government wants to shift the substitution effect to the complementary effect, it needs to improve the elasticity of debt to toll revenue.

6. Conclusion

This study constructs a two-stage theoretical model under different financing sources and debt constraints through optimal theory in China. Under different debt toll revenue elasticity conditions, the marginal effect of debt financing on maintenance has both a substitution effect and a complementary effect whether in the first stage or the second stage. Second, combined with manually collected data on toll roads, the empirical approach of time-varying difference-in-differences is used to estimate the policy effect of tollway bonds on maintenance expenditure in China, and thereby to further explore the mechanism to unify the theoretical model. The empirical results support evidence that the policy of tollway bonds has a significant effect on maintenance expenditure, and increases local government maintenance investment. Moreover, the increase in maintenance expenditure is driven by passive maintenance, that is, spending responsibilities of local governments, rather than the government's active maintenance or policy preference. Finally, we discuss that the relationship between the proportion of debt to expenditure and the ratio of maintenance expenditure in different group, and the coefficient difference between the two different groups is discussed, and the theoretical hypothesis of this paper is further verified by factual data. The empirical results confirm the substitution effect in the first stage as well as narrow the substitution effect with the reduction of debt cost in the second stage. These results further verify and enrich the hypotheses of the theoretical model.

Due to China's unilateral pursuit of construction scale and speed in the past, it has neglected the quality and efficiency of road infrastructure. The financing model of tollway bonds can effectively alleviate the problem of emphasizing construction and neglecting maintenance, which is a good reference for developing countries with constrained budgets. However, some challenges cannot be ignored in China. On the one hand, governments need to optimize the financing structure, regulate the bank loan scale, prevent potential risks, and guarantee reasonable financing requirements. At the same time, there is an urgent need to resolve the huge debt stock. How to effectively transform the substitution effect into the complementary effect would be an interesting and meaningful future research angle. On the other hand, the public sector should change passive maintenance to active maintenance. Road maintenance should gradually be converted from necessary maintenance to preventive maintenance, and temporary maintenance to long-term maintenance. Furthermore, China should avoid distortions in resource allocation and promote the sustainable development of its transportation infrastructure.

Conflict of Interest

None.

Acknowledgments

We acknowledge financial support from the Major Program of National Social Science Foundation of China (Grant No. 20ZDA084); the Key Program of National Natural Science Foundation of China (Grant No. 71934001); the National Natural Science Foundation of China (Grant Nos. 71934001, 71471001, 72104028, 41771568, and 71533004); the National Key Research and Development Program of China (Grant No. 2016YFA0602500); the Strategic Priority Research Program of the Chinese Academy of Sciences (Grant No. XDA23070400); and the Sichuan Province Social Science High Level Research Team Building in China.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ecosys.2022.101049.

References

Agénor, P.R., 2009. Infrastructure investment and maintenance expenditure: Optimal allocation rules in a growing economy. J. Public Econ. Theory 11 (2), 233–250.
Anastasopoulos, P.C., Florax, R.J.G.M., Labi, S., Karlaftis, M.G., 2010. Contracting in highway maintenance and rehabilitation: Are spatial effects important. Transp. Res. A 44 (3), 136–146.
Andani, I.G.A., La Paix Puello, L., Geurs, K., 2019. Effects of toll road construction on local road projects in Indonesia. J. Transp. Land Use 12 (1), 179–199.
Arif, U., Javid, M., Khan, F.N., 2021. Productivity impacts of infrastructure development in Asia. Econ. Syst. 45 (1), 100851.
Banerjee, A., Duflo, E., Qian, N., 2020. On the road: Access to transportation infrastructure and economic growth in China. J. Dev. Econ. 145, 102442.
Beck, T., Levine, R., Levkov, A., 2010. Big bad banks? The winners and losers from bank deregulation in the United States. J. Fin. 65 (5), 1637–1667.
Behr, P., Sonnekalb, S., 2012. The effect of information sharing between lenders on access to credit, cost of credit, and loan performance-Evidence from a credit registry introduction. J. Bank. Fin. 36 (11), 3017–3032.
Bock, M., Cardazzi, A., Humphreys, B.R., 2021. Where the Rubber Meets the Road: Pavement Damage Reduces Traffic Safety and Speed. NBER Work. 29176.
Bogart, D., 2009. Turnpike trusts and property income: New evidence on the effects of transport improvements and legislation in eighteenth-century England 1. Econ. Hist. Rev. 62 (1), 128–152.
Brach, A., Wachs, M., 2005. Earmarking in the US Department of Transportation research programs. Transp. Res. A 39 (6), 501–521.
Cai, X., Lu, Y., Wu, M., Yu, L., 2016. Does environmental regulation drive away inbound foreign direct investment? Evidence from a quasi-natural experiment in China. J. Dev. Econ. 123, 73–85.
Calthrop, E., Proost, S., 1998. Road transport externalities. Environ. Resour. Econ. 11 (3), 335–348.
Chen, J.D., Chen, J.T., Miao, Y., Song, M.L., Fan, Y.J., 2016. Unbalanced development of inter-provincial high-grade highway in China: Decomposing the Gini coefficient. Transp. Res. 48 (Oct.), 499–510.
Chen, S.X., 2017. The effect of a fiscal squeeze on tax enforcement: Evidence from a natural experiment in China. J. Public Econ. 147, 62–76.
Chen, Z., He, Z., Liu, C., 2020. The financing of local government in China: Stimulus loan wanes and shadow banking waxes. J. Financ. Econ. 137 (1), 42–71.
Chitra, T., 2003, Life based maintenance policy for minimum cost, in: Annual Reliability and Maintainability Symposium, 2003. IEEE, pp. 470–474.
Condeço-Melhorado, A., Tillema, T., de Jong, T., Koopal, R., 2014. Distributive effects of new highway infrastructure in the Netherlands: the role of network effects and spatial spillovers. J. Transp. Geogr. 34, 96–105.
Cravioto, J., Yamasue, E., Okumura, H., Ishihara, K.N., 2013. Road transport externalities in mexico: Estimates and international comparisons. Transp. Policy 30 (v), 63–76.
de Dios Ortúzar, J., Bascuñán, R., Rizzi, L.I., Salata, A., 2021. Assessing the potential acceptability of road pricing in Santiago. Transp. Res. A 144, 153–169.
De Soyres, F., Mulabdic, A., Ruta, M., 2020. Common transport infrastructure: A quantitative model and estimates from the Belt and Road Initiative. J. Dev. Econ. 143, 102415.
Égert, B., 2015. Public debt, economic growth and nonlinear effects: Myth or reality? J. Macroecon 43, 226–238.
Ferrari, P., 2002. Road network toll pricing and social welfare. Transp. Res. B 36 (5), 471–483.
Hall, J.D., Savage, I., 2019. Tolling roads to improve reliability. J. Urban Econ. 113, 103187.
Hamilton, C.J., Eliasson, J., 2013. Costs and benefits of the European directive on road tolling interoperability. Transp. Res. C. 30 (May), 221–238.
Harvey, M.O., 2012. Optimizing road maintenance. International Transport Forum Discussion Papers. OECD Publishing,.
Heggie, I.G., 1999. Commercially managed road funds: Managing roads like a business, not like a bureaucracy. Transportation 26 (1), 87–111.
Jin, L., Zhang, Z., Song, J., 2020. Profit allocation and subsidy mechanism for public–private partnership toll road projects. J. Manag. Eng. 36 (3), 04020011.
Jullien, A., Dauvergne, M., Cerezo, V., 2014. Environmental assessment of road construction and maintenance policies using LCA. Transp. Res. D. 29, 56–65.
Kalaitzidakis, P., Kalyvitis, S., 2004. On the macroeconomic implications of maintenance in public capital. J. Public Econ. 88 (3–4), 695–712.
Kaminsky, J.A., 2018. National culture shapes private investment in transportation infrastructure projects around the globe. J. Constr. Eng. Manag. 144 (2), 04017098.
López-Pita, A., Teixeira, P.F., Casas, C., Bachiller, A., Ferreira, P.A., 2008. Maintenance costs of high-speed lines in Europe state of the art. Transp. Res. Rec. 2043 (1), 13–19.
Mahdavi, S., 2004. Shifts in the composition of government spending in response to external debt burden. World Dev. 32 (7), 1139–1157.
Mathew, B.S., Isaac, K.P., 2014. Optimisation of maintenance strategy for rural road network using genetic algorithm. Int. J. Pavement Eng. 15 (4), 352–360.
Menezes, F., Ryan, M., 2015. Default and renegotiation in public-private partnership auctions. J. Public Econ. Theor. 17 (1), 49–77.
Moreno-Quintero, E., Fowkes, T., Watling, D., 2013. Modelling planner–carrier interactions in road freight transport: Optimisation of road maintenance costs via overloading control. Transp. Res. E 50, 68–83.
Odeck, J., 2019. Estimating and predicting the operational costs of road tolls: An econometric assessment using panel data. Transp. Res. A 130, 466–478.
Rioja, F.K., 2003. Filling potholes: Macroeconomic effects of maintenance versus new investments in public infrastructure. J. Public Econ. 87 (9–10), 2281–2304.
Rouse, P., Chiu, T., 2009. Towards optimal life cycle management in a road maintenance setting using DEA. Eur. J. Oper. Res. 196 (2), 672–681.
Rouwendal, J., Verhoef, E.T., 2006. Basic economic principles of road pricing: from theory to applications. Transp. Policy 13 (2), 106–114.
Santos, G., 2017. Road fuel taxes in Europe: Do they internalize road transport externalities? Transp. Policy 53, 120–134.
Shamdasani, Y., 2021, Rural road infrastructure & agricultural production: Evidence from India. J. Dev. Econ., 102686.
Shi, S., Yin, Y., Guo, X., 2016. Optimal choice of capacity, toll and government guarantee for build-operate-transfer roads under asymmetric cost information. Transp. Res. B 85 (Mar), 56–69.
Song, J., Zhao, Y., Jin, L., Sun, Y., 2018. Pareto optimization of public–private partnership toll road contracts with government guarantees. Transp. Res. A 117, 158–175.
Wing, C., Simon, K., Bello-Gomez, R.A., 2018. Designing difference in difference studies: Best practices for public health policy research. Annu. Rev. Public Health 39, 453–469.
Winston, C., Yan, J., 2011. Can privatization of US highways improve motorists' welfare? J. Public Econ. 95 (7–8), 993–1005.
Xu, M., Wang, G., Grant-Muller, S., Gao, Z., 2017. Joint road toll pricing and capacity development in discrete transport network design problem. Transportation 44 (4), 731–752.
Yan, X., Chong, H.Y., Sheng, Z., Wang, X., 2017. Financing decision model for toll roads: Balancing economic and public attributes. J. Manag. Eng. 33 (4), 04017010.
Zietlow, G.J., 2006, Role of the Private Sector in Managing and Maintaining Roads. Chapter, 15, pp. 347–371.