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Accelerated depreciation and investment-driven growth: a Marx-Okishio approach

Chong Liu[1] · **Bangxi Li**[2] · **Jim Huangnan Shen**[3]

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Abstract
Accelerated depreciation of fixed assets is a representative tax reduction policy. While existing empirical studies have primarily focused on the micro perspective, there is a lack of literature systematically quantifying its macro-level economic impact. Based on Marxist political economy and drawing on Okishio's theory of accumulation, we propose an analysis framework integrating the reproduction of fixed capital into the overall reproduction of aggregate social capital. This study aims to examine whether, and to what extent, accelerated depreciation can promote economic growth, using China's input-output data from 1981 to 2020. The findings reveal that accelerated depreciation positively impacts economic growth, primarily driven by new investments. This impact becomes more significant as the depreciation period shortens. However, it is essential to note that shortening the depreciation period also leads to a negative adjustment effect due to increased costs. Theoretical implications for policymaking need a systematic perspective on the role of accelerated depreciation and investment-driven growth.

Keywords Accelerated depreciation · Fixed capital · Investment-driven growth · Marx-Okishio approach

JEL Classification B51 · E62 · L60

✉ Bangxi Li
libangxi@tsinghua.edu.cn

Chong Liu
cl2009@cam.ac.uk

Jim Huangnan Shen
hnshen@fudan.edu.cn

1 Department of Land Economy, University of Cambridge, 19 Silver Street, Cambridge CB3 9EP, United Kingdom

2 School of Social Sciences, Tsinghua University, Tsinghua University, Room 220, Mingzhai Building, Beijing 100084, China

3 School of Management, Fudan University, Fudan University, Room 415, Siyuan Building, Shanghai 200433, China

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1 Introduction

Over the past decade, China's economic growth has reached a point where an apparent contradiction between supply and demand has emerged. While low interest rates and high local government debt have limited the effectiveness of demand-side monetary and fiscal policies, supply-side tax reduction policies have become effective tools for macroeconomic regulation. By June 2019, China had issued 89 tax reduction policies to alleviate the burden on firms, especially those in the manufacturing sectors. One such tax reduction policy targeting the manufacturing sectors is the accelerated depreciation of fixed assets. This policy plays an important role in the development of several industrial and economic networks in China, including energy transmission, cargo transport, and information technology. Notably, it provides numerous benefits to companies, such as allowing them to deduct accelerated depreciation on fixed assets and improving cash flows by reducing current income taxes. Therefore, it is essential to examine the impact of this tax reduction policy on overall economic growth.

Although the literature attempts to address whether tax reduction policies promote investment, both theoretical and empirical studies have been inconclusive, leaving this question controversial. On the one hand, theoretical analyses rely on trade-offs between different mechanisms. Hall and Jorgenson (1967) construct a theoretical model to analyze the impact of tax reduction policies on investment, considering the increase in the present value of tax incentives as the main influencing factor. However, Edgerton (2012) shows that shareholders and managers focus on profit-making rather than on increased cash flows influenced by accelerated depreciation. On the other hand, varying data and estimation methods lead to varying empirical results. For instance, while early studies demonstrated a significant impact of tax reduction policies (Auerbach and Hassett 1992), later studies have provided evidence of cross-sectional differences regarding the effect of tax reduction policies on investment (Cummins et al. 1995; Hassett and Hubbard 2002; House and Shapiro 2008; Hamaaki 2008; Zwick and Mahon 2017). Chirinko et al (1999) argue that the effect is weak, while other researchers have qualified the effect to some extent. For example, Yagan (2015) finds the policy to be beneficial only for some firms in the United States of America (USA), and Garrett et al (2020) claim that regions with a large decrease in investment costs experience a greater increase in employment and income.

All the aforementioned studies discuss short-term enterprise behavior at the micro-level. However, it is impossible to eliminate the endogenous disturbance of long-term cyclical fluctuations at the macro-level. Governments typically implement tax reduction policies during downturns, and investment decisions made by firms are tied to economic trends. Therefore, a comprehensive understanding of the economic impact of tax reduction policies necessitates a macro-level perspective. Okishio's theorem of accumulation provides a compelling framework for such an analysis. Situated at the intersection of Marxian reproduction schema and post-Keynesian growth theory, it emphasizes equilibrium accumulation trajectory, which reflects the optimal dynamics that the reproduction process is expected to follow. This framework enables the construction of economic models that can evaluate the impact of accelerated depreciation on overall economic growth. Simulation can be used to quantify the policy's contribution to economic growth. In the context of industrial transformation and upgrading, governments implement tax reduction policies for enterprises to enhance investment and thereby stimulate economic growth. Hence, it is important to assess whether tax reduction policies promote economic growth. However, this topic has received little attention in the literature.

Firstly, the studies primarily focus on developed countries, such as the USA, and thus provide limited evidence on developing countries like China. The tax reduction policy in China has not been thoroughly discussed (Zhang et al. 2018). Only a few scholars have considered the accelerated depreciation policy as a quasi-natural experiment and constructed a difference-in-differences (DID) model for empirical research (Cao and Chen 2017; Liu et al. 2019). Nevertheless, it is crucial to consider the differences between China and the USA. For example, accelerated depreciation in China allows for a shorter depreciation period, which helps firms obtain greater tax incentives. The second deficiency pertains to the estimation method used to describe the role of the value-added tax reform. This aspect has only been considered in recent years. In this regard, some scholars have discussed the impact of income tax reform (Ackermann et al. 2016; Zwick and Mahon 2017; Ohrn 2019; Maffini et al. 1957; Garrett et al. 2020). The Chinese government levies two types of taxes—indirect taxes (value-added tax, business tax, and consumption tax) and direct taxes (enterprise income tax and individual income tax). While there have been several analyses on the former (Cai and Harrison 2011; Wang 2013; Liu and Lu 2015; Zhang et al. 2018), there have been few studies on the latter. However, research on the accelerated depreciation policy can fill the gap in studies on the latter.

This study aims to determine whether tax reduction policies, specifically accelerated depreciation, can promote economic growth. While the aforementioned models made no distinction between fixed capital and general means of production inputs, our new model distinguishes between these two and extends the general framework to simulate accelerated depreciation. To estimate the impact of accelerated depreciation on the growth potential of China's gross domestic product (GDP), the study uses official input-output data from 1981 to 2020. The results show that accelerated depreciation positively influences economic growth through its effect on investment; specifically, it exerts a promotion effect that becomes more significant with shorter depreciation periods, but is limited by the asset structure. This study also discusses potential situations in which tax incentives are not used for enterprise investment. It finds that shortened depreciation periods lead to changes in economic accounting that have a negative adjustment effect on economic growth. Thus, a positive investment effect is necessary to offset the accounting adjustments and promote economic growth. In this manner, we contribute to the literature by providing a theoretical basis for the formulation and implementation of tax reduction policies, such as accelerated depreciation in China, and offer effective suggestions for improving the quality and sustainability of economic growth.

The remainder of the paper is presented as follows. Section 2 presents the policy background. Section 3 illustrates a systematic framework inspired by Okishio. Section 4 details the construction and extension of the model, as well as the basic processing of the input-output data. Section 5 conducts a simulation test and explains accelerated depreciation. Section 6 presents the conclusion and proposals for possible further research.

2 Policy background

In 2014, the Ministry of Finance and the State Taxation Administration jointly issued *The Notice on Improving the Income Tax Policy for Accelerated Depreciation of Fixed Assets* (Caishui [2014] No. 75) (otherwise known as *The Notice*). It targeted two categories of fixed assets. The first category consists of fixed assets specifically used for research and development across all industries. The second category includes newly purchased fixed assets in six specific industries, including biopharmaceutical manufacturing. Subsequently, Caishui [2015] No. 106 expanded this to four additional areas—light industry, textiles, machinery, and automobiles—and it was eventually expanded to all manufacturing sectors by Caishui [2019] No. 66. This expansion was also reflected in the *Government Work Reports* of 2019, 2022, and 2023.

For firms, a reduction in taxable income is equivalent to obtaining an interest-free loan. Although the total amount of depreciation on fixed assets continues to remain unchanged, the publication of *The Notice* (2014) has led to an increase in depreciation in the current period of purchase. The greater the depreciation in the current period, the greater the tax incentive enjoyed by enterprises. While general depreciation of fixed assets is calculated using the straight-line (SL) method, accelerated depreciation is calculated using the double declining balance (DDB) or the sum-of-the-years' digits (SYD) method. Furthermore, the depreciation period may be shortened to 60% of its minimum, as specified in the *Regulations for the Implementation of the Enterprise Income Tax Law of the People's Republic of China* (2007) (otherwise known as *The Regulations*). This can be exemplified through a scenario wherein an enterprise purchases $600,000 worth of fixed assets; in this case, the tax incentives for the general and accelerated depreciation can be calculated and compared (Table 1).

Different methods of accelerated depreciation result in different tax incentives. In Table 1, under the "Present Value" column, accelerated depreciation significantly increases the tax incentives for firms. However, in the absence of discounting, accelerated depreciation does not change the total amount of depreciation shown in the "Total" column. In this case, the tax preference is only related to the enterprise income tax rate, and there is no difference between the methods of accelerated depreciation. The change occurs only in the timing of depreciation, effectively accelerating it. In the current and early periods, accelerated depreciation deductions exceed those of general depreciation, effectively increasing the present value of tax preferences.

Table 1 Tax incentives for general depreciation and accelerated depreciation

Year	1	2	3	4	5	6	7	8	9	10	Total	Present Value
General Depreciation												
SL method												
Deductions	60	60	60	60	60	60	60	60	60	60	600	
Tax Incentives	15	15	15	15	15	15	15	15	15	15	150	112.73
Accelerated Depreciation												
DDB method												
Deductions	120	96	77	61	49	39	31	25	50	50	600	
Tax Incentives	30	24	19	15	12	10	8	6	13	13	150	121.44
SYD method												
Deductions	109	98	87	76	65	55	44	33	22	11	600	
Tax Incentives	27	25	22	19	16	14	11	8	5	3	150	124.08
Shortening												
Deductions	100	100	100	100	100	100	0	0	0	0	600	
Tax Incentives	25	25	25	25	25	25	0	0	0	0	150	127.50

The Present Value is calculated to determine the current worth of future tax incentives by summing each future value discounted back to the present. Assuming a depreciation period of 10 years, we adopt an enterprise income tax rate in China of 25% (Liu et al. 2019) and a discount rate of 7% (Zwick and Mahon 2017). Additionally, we estimate different enterprise income tax rates and discount rates in this paper, which do not influence the above conclusions. Author's calculations

By calculating the increased rate of tax incentives obtained from the accelerated over general depreciation, we can obtain the effectiveness of the three methods of accelerated depreciation—DDB method ($121.44 \div 112.73 - 1 = 7.73\%$), SYD method ($124.08 \div 112.73 - 1 = 10.07\%$), and shortening the depreciation period ($127.50 \div 112.73 - 1 = 13.10\%$). Shortening the depreciation period yields the best performance, indicating that firms are more likely to choose this method. This leads to the question of whether firms are inclined to choose this method of accelerated depreciation for any fixed assets. According to Article 60 of *The Regulations*, fixed assets and their depreciation periods are grouped into five categories:

1. Houses and buildings: 20 years
2. Aircraft, trains, ships, machinery, and other production equipment: 10 years
3. Tools related to production and business activities: 5 years
4. Means of transport, other than aircraft, trains, and ships: 4 years
5. Electronic equipment: 3 years

In the given context, this study examines the influence of the minimum depreciation period on the tax incentives estimated using different methods of accelerated depreciation, as shown in Fig. 1.

Shortening the depreciation period is considered the optimal solution for Chinese firms to reduce the cost of investing in fixed assets. In the case where governments do not allow the shortening of the depreciation period, firms adopt the principle of "general depreciation for economic accounting and accelerated depreciation for

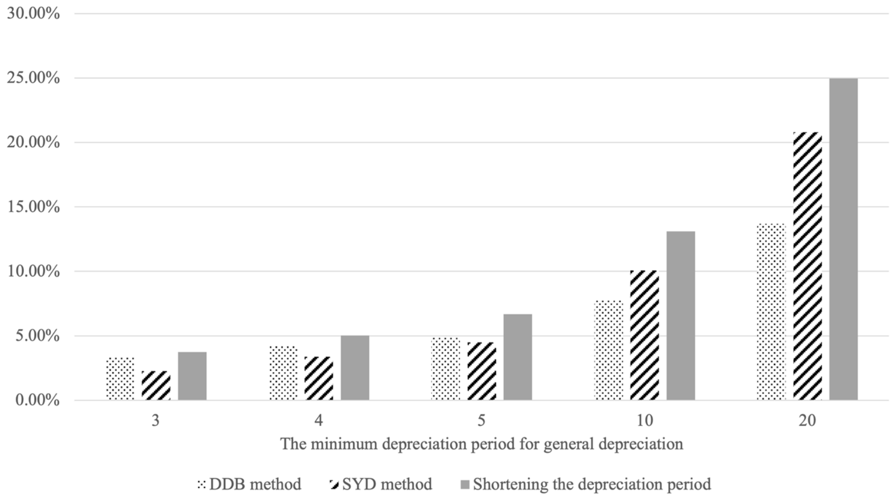

Fig. 1 Effectiveness of Tax Incentives with Different Methods of Accelerated Depreciation. Source: Author's calculations

tax purposes" (Moonitz 1957; Hill 1957). Thus, some scholars have discussed the choice between the DDB and the SYD methods (Davidson and Drake 1961, 1964). The conclusion is that, as shown in Fig. 1, firms with short-term asset structures should use the former, while firms with long-term asset structures should use the latter. Conversely, shortening the depreciation period is more effective, irrespective of whether the asset structure is short- or long-term; this is a unique feature of the income tax reform in China.

In this study, the simulation of accelerated depreciation focuses on three aspects related to shortening the depreciation period: the first two pertain to firms' choices regarding this method, and the third addresses a gap in the literature. First, firms aiming to minimize costs will choose the method that offers the highest tax incentives. Second, firms can distinguish between short- and long-term asset structures. As shown in Fig. 1, the longer the depreciation period, the greater the additional tax incentives earned through accelerated depreciation. Third, due to limited data on estimation methods, few studies have discussed the impact of shortening the depreciation period on economic growth; this gap will be addressed in this discussion.

3 Theoretical analysis framework after Okishio

To systematically study the influence of accelerated depreciation, we draw upon Okishio's analytical framework. Okishio (1967), in the Chapter 2 of his monograph *The Theory of Accumulation* (in Japanese), investigated the coordinated process of expanding reproduction and proposed an "equilibrium" accumulation trajectory, an ideal path that an economy must follow for long-term expanding reproduction without considering the unbalanced disturbances that frequently occur in reality. This provides a basic analytical framework for examining whether accelerated depreciation affects economic growth through investment. However, Shaikh (1978) noted that Okishio's model only includes general means of production and has not been adequately extended to the case of fixed capital. Reflecting on Shaikh's research, Roemer (1979), Alberro and Persky (1979), and Bidard (1988) have attempted to extend it to cases involving fixed capital. In fact, Okishio (1975) also considered the issue of fixed capital, but this work is rarely known to scholars because it was published only in Japanese. Overall, Okishio's model is mathematically robust enough to be effectively extended to joint production with fixed capital under certain conditions (Li et al. 2018). We continue this line of thought by introducing the Marx-Okishio approach to study the macro-economic impacts of accelerated depreciation under equilibrium conditions. The specific model, including how it follows or modifies Okishio's original assumptions, is presented in the next section. Here, we just illustrate the analytical framework using a simplified scenario.

For simplicity, in the basic GDP accounting identity, depreciation plays two roles—cost and profit, and accelerated depreciation simultaneously increases both. The GDP of a closed economy can be calculated using the expenditure approach and the income approach as follows:

$$Y = I + C_{\Pi} + C_W + G \tag{1}$$

$$Y = \Pi + W + D^N + T \tag{2}$$

where I represents total investment, C_{Π} and C_W represent total consumption by capitalists and workers respectively, G represents total government expenditure, Π represents total profit, W represents total wages, D^N represents nominal depreciation, and T represents total taxes.

It is necessary to distinguish between capitalists and workers because their sources of income and consumption propensities differ. Assume that capitalists do not participate in productive labor. Their income comes from the unpaid appropriation of surplus value created by workers. A certain proportion α of this income is used for investment, and the rest for consumption. Workers' income—wages (considering production relations and technological levels)—only maintains the minimum level necessary for labor force reproduction, and all of it is consumed without any savings. Therefore:

$$C_{\Pi} = (1 - \alpha)\Pi \tag{3}$$

$$C_W = W \tag{4}$$

Substituting (3) and (4) into (1) and (2), we get:

$$I + G = \alpha\Pi + D^N + T \tag{5}$$

If taxes and government expenditure are balanced, i.e., $G = T$, then:

$$I = \alpha\Pi + D^N \tag{6}$$

Eq. (6) can be understood as total investment being equal to total savings.

Define capital K and consider its increment ΔK, which is total investment minus actual depreciation:

$$\Delta K = I - D^R \tag{7}$$

Define the growth rate g:

$$g = \frac{\Delta K}{K} = \frac{I - D^R}{K} = \frac{\alpha\Pi + D^N - D^R}{K} = \alpha r + d^N - d^R \tag{8}$$

where $r = \Pi/K$ is the profit rate, $d^N = D^N/K$ is the nominal depreciation rate, and $d^R = D^R/K$ is the actual depreciation rate, all with capital stock as the denominator. It should be noted that this is an extension of the Cambridge Formula. At this point, accelerated depreciation affects the growth rate since $d^N - d^R > 0$, where the nominal depreciation rate exceeds the actual depreciation rate, transforming part of the nominal depreciation into renewal investment.

However, profit (and thus the profit rate) is still a function of depreciation, and Eq. (8) can be further decomposed. Given that total profit $\Pi = Y - W - D^N - T$, and total wages and total taxes can be determined by the actual wage parameter per unit of labor w, the labor input coefficient per unit of output l, and the average tax rate t:

$$W = wlY \tag{9}$$

$$T = t\left(Y - W - D^N\right) \tag{10}$$

Thus:

$$\Pi = (1 - t)\left[(1 - wl)Y - D^N\right] \tag{11}$$

Correspondingly, we have:

$$\frac{\Pi}{K} = \frac{(1 - t)\left[(1 - wl)Y - D^N\right]}{K} = (1 - t)\left[(1 - wl)\frac{Y}{K} - \frac{D^N}{K}\right] \tag{12}$$

$$r = (1 - t)\left[(1 - wl)\sigma - d^N\right] \tag{13}$$

where σ is the output per unit of capital.

Finally, the relationship between the growth rate and the depreciation rate is as follows:

$$g = \alpha(1 - t)(1 - wl)\sigma - \alpha(1 - t)d^N + \left(d^N - d^R\right) \tag{14}$$

Capital Accumulation (+) Adjustment Effect (−) Investment Effect (+)

Promotion Effect (+)

Eq. (14) demonstrates that when depreciation is accelerated, an increase in the nominal depreciation rate negatively affects the growth rate. The primary mechanism behind this is the adjustment of total production costs, referred to in this paper as the adjustment effect. The change in total investment reflects its divergence from the actual depreciation rate.

The investment effect of tax reduction policy is widely debated among scholars. However, this is only one aspect; the difference between the investment and promotion effects has garnered comparatively less attention. The existing literature has seldom conducted systematic research on accelerated depreciation. One of the innovations of this study is to establish a theoretical analysis framework, as shown in Fig. 2. The process and promotion effects of accelerated depreciation can be divided into two phases wherein the general depreciation initially exerts a negative adjustment effect on economic accounting and a long-term equilibrium is achieved through a positive investment effect.

However, the aforementioned identities only capture the cost (and consequently profit) changes due to accelerated depreciation at the level of growth accounting, thereby illustrating the existence of the adjustment effect. For a quantitative assessment of the macroeconomic performance of the accelerated depreciation policy, this approach is overly simplistic, as it omits the methods, duration, and sector-specific applications of accelerated depreciation. This necessitates a more complex model, which will be developed in the next section.

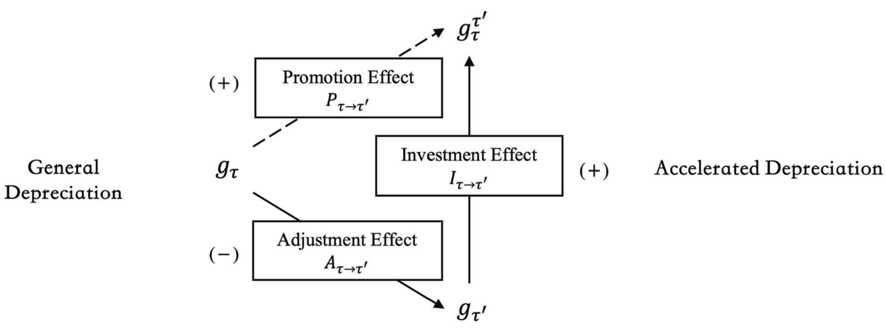

Fig. 2 Theoretical analysis framework

4 Model construction and extension

Based on Marxist political economy and drawing on Okishio's theory of accumulation, the reproduction of fixed capital can be embedded in the reproduction of aggregate social capital. The value of fixed capital gradually transfers to the circuit of goods or services. This transfer represents the decline in the value of fixed assets, which is known as depreciation of fixed capital. It is also considered a fund that compensates for the transferred value. The influence of fixed capital is reflected not only through technical conditions but also through continual changes in production and income distribution structures. Li and Zhao (2017) show that, on the supply side, the influence of fixed capital usually precedes the means of production. In this context, it is necessary to simulate the effect of fixed capital compensation on reproduction in order to investigate whether accelerated depreciation can promote economic growth. Our model assumes that the entire production process comprises the means of production and consumption, and thus fixed capital cannot be distinguished separately. However, the role of fixed capital in the reproduction process is gradual, continuous, and precursory. Therefore, this study constructs and extends a *reproduction* model with three major sectors to distinguish fixed capital from general means of production, based on the reproduction schema with two major sectors. By changing certain important parameters, we simulate accelerated depreciation and quantify the level of economic growth in China once the reproduction reaches equilibrium.

4.1 Constructing a structure table of three major sectors using the input-output data

Previous studies, notably Lange (1962), have validated the transformation relationship between input-output data and the two-sector reproduction schema, which is highly pertinent to this research. Specifically, this validation provides a foundation for constructing a structural table of three major sectors, thereby enabling the separation of fixed capital from general means of production. Furthermore, Li et al (2019) have discussed data processing methods, which are briefly introduced in this subsection.

Let the shares of the product input in the three major sectors be α_i, β_i, and γ_i; their calculation formulas are as follows:

$$\alpha_i = \frac{S_i}{H_i}, \beta_i = \frac{\sum_{j=1}^{n} x_{ij} + \Delta a_i}{H_i}, \gamma_i = \frac{C_i}{H_i} \tag{15}$$

where x_{ij} is the input from sector i to sector j; S_i, Δa_i, and C_i represent the fixed capital formation, the inventory increase, and the consumption of sector i, respectively; and H_i is the total domestic demand. Excluding of international trade: $H_i = S_i + \sum_{j=1}^{n} x_{ij} + \Delta a_i + C_i$, the input between sectors should be divided into three major sectors and then added.

The depreciation of fixed capital, the input of general means of production, and the total output of the three major sectors are denoted by k_m^*, a_m, and Y_m, respectively, where $m = I, II, III$ to indicate the major sectors. The calculation formulas are as follows:

$$k_I^* = \sum_{i=1}^{n} \alpha_i \Delta k_i, k_{II}^* = \sum_{i=1}^{n} \beta_i \Delta k_i, k_{III}^* = \sum_{i=1}^{n} \gamma_i \Delta k_i \tag{16}$$

$$a_I = \sum_{i=1}^{n} \sum_{j=1}^{n} \alpha_i x_{ij}, a_{II} = \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_i x_{ij}, a_{III} = \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_i x_{ij} \tag{17}$$

$$Y_I = \sum_{i=1}^{n} \alpha_i x_i, Y_{II} = \sum_{i=1}^{n} \beta_i x_i, Y_{III} = \sum_{i=1}^{n} \gamma_i x_i \tag{18}$$

where Δk_i and x_i, respectively, represent the depreciation of fixed capital and the total output of sector i. Additionally, s_i and w_i represent the profits and wages in the input-output table. The profits and wages of the three major sectors Π_m and W_m are calculated as follows:

$$\Pi_I = \sum_{i=1}^{n} \alpha_i s_i, \Pi_{II} = \sum_{i=1}^{n} \beta_i s_i, \Pi_{III} = \sum_{i=1}^{n} \gamma_i s_i \tag{19}$$

$$W_I = \sum_{i=1}^{n} \alpha_i w_i, W_{II} = \sum_{i=1}^{n} \beta_i w_i, W_{III} = \sum_{i=1}^{n} \gamma_i w_i \tag{20}$$

We can express the total capital formation S, the accumulation of general means of production K, and the consumption C as follows:

$$S = \sum_{i=1}^{n} S_i, K = \sum_{i=1}^{n} \Delta a_i, C = \sum_{i=1}^{n} C_i \tag{22}$$

The above model is extended to the open economy by using $\left(E_m - M_m\right)$ to represent the net exports of these three major sectors. Subsequently, we construct Table 2, indicating the production structure of the three major sectors.

Table 2 Structural table of the three major sectors

	I	II	III	Final Demand	Net Export	Total Output
I	(k_I^*)	(k_{II}^*)	(k_{III}^*)	S	$E_I - M_I$	Y_I
II	a_I	a_{II}	a_{III}	K	$E_{II} - M_{II}$	Y_{II}
III	0	0	0	C	$E_{III} - M_{III}$	Y_{III}
Profit	Π_I	Π_{II}	Π_{III}			
Wage	W_I	W_{II}	W_{III}			
Total Input	Y_I	Y_{II}	Y_{III}			

4.2 Model construction

In our model, the production price system is defined as follows:

$$\boldsymbol{pB} = (1 + r)\boldsymbol{pM} \tag{23}$$

where the vector $\boldsymbol{p}$ is the relative production price (this needs to satisfy the non-negative condition); r is the average profit rate, and matrices $\boldsymbol{M}$ and $\boldsymbol{B}$, respectively, reflect the input and output.

Then, we expand Eq. (23):

$$\boldsymbol{pB} = (1 + r)\boldsymbol{pM}, \boldsymbol{M} = \boldsymbol{A} + c\boldsymbol{FL} \tag{24}$$

where $\boldsymbol{A}$ is the input coefficient matrix for means of production, composed of k_1 to k_3, which represent the quantities of fixed capital required to reproduce one unit of product in each of the three major sectors, and a_1 to a_3, which represent the quantities of general means of production required. c is the real wage rate, reflecting the structure of the income distribution (the real wage rate is later standardized). $\boldsymbol{F}$ is the wage product vector, and $\boldsymbol{L}$ is the labor input coefficient vector, consisting of l_1 to l_3, which represent the labor inputs required to reproduce one unit of product in each of the three major sectors. $\boldsymbol{B}$ is the corresponding output coefficient matrix. They are expressed below:

$$\boldsymbol{A} = \begin{pmatrix} k_1 & 0 & \cdots & 0 & k_2 & 0 & \cdots & 0 & k_3 & 0 & \cdots & 0 \\ 0 & k_1 & & & 0 & k_2 & & & 0 & k_3 & & \\ \vdots & & \ddots & & \vdots & & \ddots & & \vdots & & \ddots & \\ 0 & & & k_1 & 0 & & & k_2 & 0 & & & k_3 \\ a_1 & \cdots & \cdots & a_1 & a_2 & \cdots & \cdots & a_2 & a_3 & \cdots & \cdots & a_3 \\ 0 & \cdots & \cdots & 0 & 0 & \cdots & \cdots & 0 & 0 & \cdots & \cdots & 0 \end{pmatrix}_{(\tau+2)\times 3\tau}$$

$$\boldsymbol{F} = \begin{pmatrix} 0 \\ \vdots \\ 0 \\ f \end{pmatrix}_{(\tau+2)\times 1}$$

$$\boldsymbol{L} = \begin{pmatrix} l_1 & \cdots & l_1 & l_2 & \cdots & l_2 & l_3 & \cdots & l_3 \end{pmatrix}_{1\times 3\tau}$$

$$\boldsymbol{B} = \begin{pmatrix} 1 & \cdots & \cdots & 1 & 0 & \cdots & \cdots & 0 & 0 & \cdots & \cdots & 0 \\ k_1 & & & & k_2 & & & & k_3 & & & \\ & \ddots & & & & \ddots & & & & \ddots & & \\ & & k_1 & 0 & & & k_2 & 0 & & & k_3 & 0 \\ 0 & \cdots & \cdots & 0 & 1 & \cdots & \cdots & 1 & 0 & \cdots & \cdots & 0 \\ 0 & \cdots & \cdots & 0 & 0 & \cdots & \cdots & 0 & 1 & \cdots & \cdots & 1 \end{pmatrix}_{(\tau+2)\times 3\tau}$$

Using the data from Table 2 and the methods introduced in Li et al (2019), the above parameters can be calculated; the detailed calculation is omitted here.

It is evident, from the change in the matrix structure from $\boldsymbol{M}$ to $\boldsymbol{B}$, that the value transfer of fixed capital participating in reproduction is accompanied by an increase in service age, which corresponds to depreciation. This observation can be traced back to Sraffa (1960) distinguishing fixed capital according to service age. For example, in the case of newly acquired fixed capital (service age is 0), only general depreciation is considered:

$$\begin{pmatrix} k_1 \\ 0 \\ \vdots \\ a_1 \\ cfl_1 \end{pmatrix} \rightarrow \begin{pmatrix} 1 \\ k_1 \\ 0 \\ \vdots \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} k_2 \\ 0 \\ \vdots \\ a_2 \\ cfl_2 \end{pmatrix} \rightarrow \begin{pmatrix} 0 \\ k_2 \\ 0 \\ \vdots \\ 1 \\ 0 \end{pmatrix}, \begin{pmatrix} k_3 \\ 0 \\ \vdots \\ a_3 \\ cfl_3 \end{pmatrix} \rightarrow \begin{pmatrix} 0 \\ k_3 \\ 0 \\ \vdots \\ 0 \\ 1 \end{pmatrix}$$

The same applies to any other service age.

We denote the general depreciation period by τ. Note that both input $\boldsymbol{M}$ and output $\boldsymbol{B}$ in the model are $(\tau + 2) \times 3\tau$ matrices. Their production structure depends only on the general depreciation period τ. We denote them as $\boldsymbol{M}_{\boldsymbol{\tau}}$ and $\boldsymbol{B}_{\boldsymbol{\tau}}$ to distinguish different asset structures. Accordingly, the general depreciation model is obtained:

$$\boldsymbol{p}\boldsymbol{B}_{\boldsymbol{\tau}} = \left(1 + r_\tau\right)\boldsymbol{p}\boldsymbol{M}_{\boldsymbol{\tau}} \tag{25}$$

Given the general depreciation period τ, if we solve the equilibrium Eq. (25), we will obtain the profit rate r_τ. Specifically, on both sides of the equation, if we post-multiply the Moore–Penrose pseudo-inverse matrix $\boldsymbol{B}_{\boldsymbol{\tau}}^{+}$ of the output coefficient matrix $\boldsymbol{B}_{\boldsymbol{\tau}}$, we obtain:

$$\lambda_\tau \boldsymbol{p} = \boldsymbol{p}\boldsymbol{M}_{\boldsymbol{\tau}}\boldsymbol{B}_{\boldsymbol{\tau}}^{+}, \lambda_\tau = \frac{1}{1 + r_\tau} \tag{26}$$

where the price vector $\boldsymbol{p}$ is the left eigenvector of matrix $\boldsymbol{M}_{\boldsymbol{\tau}}\boldsymbol{B}_{\boldsymbol{\tau}}^{+}$; then, λ_τ is the eigenvalue of matrix $\boldsymbol{M}_{\boldsymbol{\tau}}\boldsymbol{B}_{\boldsymbol{\tau}}^{+}$.

To examine the economic growth at the macro-level, the Cambridge Formula is used to translate the profit rate r_τ into the potential GDP growth rate:

$$g_\tau = \alpha r_\tau \tag{27}$$

where α is the rate of accumulation, which is the ratio of the surplus value used for the capital accumulation to the total surplus value. It can be calculated using GDP, the gross wages of employed persons Θ^*, and the gross capital formation S^*, as published by the National Bureau of Statistics of China.

4.3 Extension: how to simulate accelerated depreciation

Overall, Eq. (25) demonstrates the integration of Okishio (1967) and Okishio (1975). First, by treating each column's change from $\boldsymbol{M}_{\tau}$ to $\boldsymbol{B}_{\tau}$ as an individual equation, the scenario in which fixed capital is not distinguished within the means of production reduces to the system of equations outlined in Okishio (1967). This reduction reflects our commitment to characterizing the temporal and intersectoral relationships inherent in the reproduction process. Second, whether solving the system of equations in Okishio (1967) or determining the eigenvalues and eigenvectors of the matrix by Marx-Okishio approach, both methodologies fundamentally focus on the equilibrium accumulation trajectory. Third, as Okishio (1967) noted, the equilibrium accumulation trajectory depends on production technology, the real wage rate, and the ratio of capitalist accumulation demand to private consumption. The Marx-Okishio approach also indicates that production technology and the real wage rate determine the rate of profit, thereby establishing the potential GDP growth rate, under the assumption that capitalists do not engage in non-productive consumption. Fourth, during the depreciation process, consistent with Okishio (1975), we assume that the efficiency of fixed capital remains constant. This assumption is reflected in the fact that the parameters k_1 to k_3 in the first τ rows remain unchanged, even as the service age of fixed capital increases.

Drawing upon the Marx-Okishio approach, we consider the accelerated depreciation to extend the model. We define τ' as the accelerated depreciation period where $2 \leq \tau' \leq \tau - 1$. First, we assume that the time value of money resulting from deferred tax is fully utilized and translated into investment. In the input and output coefficient matrices, the service life of fixed capital should not exceed the accelerated depreciation period; otherwise, it would not be recognized in economic accounting. We also assume that the funding investment compensates for the value transfer, ensuring the matrix structure remains unchanged.

We define $\boldsymbol{M}_{\tau}^{\tau'}$ and $\boldsymbol{B}_{\tau}^{\tau'}$ to represent the input and output coefficient matrices of the accelerated depreciation, including investment.

For example, if the depreciation period is shortened by one year ($\tau' = \tau - 1$), the input and output coefficient matrices become:

$$\boldsymbol{M}_{\tau}^{\tau-1} = \begin{pmatrix} k_1 & 0 & \cdots & \cdots & 0 & k_2 & 0 & \cdots & \cdots & 0 & k_3 & 0 & \cdots & \cdots & 0 \\ 0 & k_1 & & & & 0 & k_2 & & & & 0 & k_3 & & & \\ \vdots & & \ddots & & & \vdots & & \ddots & & & \vdots & & \ddots & & \\ \vdots & & & k_1 & & \vdots & & & k_2 & & \vdots & & & k_3 & \\ 0 & & & & 0 & 0 & & & & 0 & 0 & & & & 0 \\ a_1 & \cdots & \cdots & \cdots & a_1 & a_2 & \cdots & \cdots & \cdots & a_2 & a_3 & \cdots & \cdots & \cdots & a_3 \\ cfl_1 & \cdots & \cdots & \cdots & cfl_1 & cfl_2 & \cdots & \cdots & \cdots & cfl_2 & cfl_3 & \cdots & \cdots & \cdots & cfl_3 \end{pmatrix}_{(\tau+2)\times 3\tau}$$

$$
\boldsymbol{B}_{\boldsymbol{\tau}}^{\boldsymbol{\tau}-1} = \begin{pmatrix}
1 & \cdots & \cdots & \cdots & 1 & 0 & \cdots & \cdots & \cdots & 0 & 0 & \cdots & \cdots & \cdots & 0 \\
k_1 & & & & & k_2 & & & & & k_3 & & & & \\
& \ddots & & & & & \ddots & & & & & \ddots & & & \\
& & k_1 & & & & & k_2 & & & & & k_3 & & \\
& & & 0 & 0 & & & & 0 & 0 & & & & 0 & 0 \\
0 & \cdots & \cdots & \cdots & 0 & 1 & \cdots & \cdots & \cdots & 1 & 0 & \cdots & \cdots & \cdots & 0 \\
0 & \cdots & \cdots & \cdots & 0 & 0 & \cdots & \cdots & \cdots & 0 & 1 & \cdots & \cdots & \cdots & 1
\end{pmatrix}_{(\tau+2)\times 3\tau}
$$

Similarly, if the depreciation period is shortened by i years and $\tau' = \tau - i$, then the fixed capital input coefficients in the matrices k_1 to k_3 will be replaced by i zeros, based on the service age, until the depreciation period is shortened to 2 years, taking $\tau' = 2$.

$$
\boldsymbol{M}_{\boldsymbol{\tau}}^{2} = \begin{pmatrix}
k_1 & 0 & \cdots & \cdots & 0 & k_2 & 0 & \cdots & \cdots & 0 & k_3 & 0 & \cdots & \cdots & 0 \\
0 & k_1 & & & & 0 & k_2 & & & & 0 & k_3 & & & \\
\vdots & & 0 & & & \vdots & & 0 & & & \vdots & & 0 & & \\
\vdots & & & \ddots & & \vdots & & & \ddots & & \vdots & & & \ddots & \\
0 & & & & 0 & 0 & & & & 0 & 0 & & & & 0 \\
a_1 & \cdots & \cdots & \cdots & a_1 & a_2 & \cdots & \cdots & \cdots & a_2 & a_3 & \cdots & \cdots & \cdots & a_3 \\
cfl_1 & \cdots & \cdots & \cdots & cfl_1 & cfl_2 & \cdots & \cdots & \cdots & cfl_2 & cfl_3 & \cdots & \cdots & \cdots & cfl_3
\end{pmatrix}_{(\tau+2)\times 3\tau}
$$

$$
\boldsymbol{B}_{\boldsymbol{\tau}}^{2} = \begin{pmatrix}
1 & \cdots & \cdots & \cdots & 1 & 0 & \cdots & \cdots & \cdots & 0 & 0 & \cdots & \cdots & \cdots & 0 \\
k_1 & & & & & k_2 & & & & & k_3 & & & & \\
& 0 & & & & & 0 & & & & & 0 & & & \\
& & \ddots & & & & & \ddots & & & & & \ddots & & \\
& & & 0 & 0 & & & & 0 & 0 & & & & 0 & 0 \\
0 & \cdots & \cdots & \cdots & 0 & 1 & \cdots & \cdots & \cdots & 1 & 0 & \cdots & \cdots & \cdots & 0 \\
0 & \cdots & \cdots & \cdots & 0 & 0 & \cdots & \cdots & \cdots & 0 & 1 & \cdots & \cdots & \cdots & 1
\end{pmatrix}_{(\tau+2)\times 3\tau}
$$

The progressive substitution of k_1 to k_3 with zero values reflects the process of accelerated depreciation. It is important to note that the actual magnitudes of k_1 to k_3 remain unchanged because we assume that the technical conditions are exogenously given for a specific year when simulating accelerated depreciation. This assumption ensures that the cost of reproducing a unit of product remains constant.

Second, we consider the cases where the tax incentives are not used for investment. In the input and output coefficient matrices, the service age of the fixed capital still does not exceed the accelerated depreciation period. However, shortening the depreciation period leads to changes in economic accounting; the matrix structure resembles that of the reproduction process with τ' as the general depreciation period.

$$
\boldsymbol{M}_{\boldsymbol{\tau}'} = \begin{pmatrix}
k_1 & 0 & \cdots & 0 & k_2 & 0 & \cdots & 0 & k_3 & 0 & \cdots & 0 \\
0 & k_1 & & & 0 & k_2 & & & 0 & k_3 & & \\
\vdots & & \ddots & & \vdots & & \ddots & & \vdots & & \ddots & \\
0 & & & k_1 & 0 & & & k_2 & 0 & & & k_3 \\
a_1 & \cdots & \cdots & a_1 & a_2 & \cdots & \cdots & a_2 & a_3 & \cdots & \cdots & a_3 \\
cfl_1 & \cdots & \cdots & cfl_1 & cfl_2 & \cdots & \cdots & cfl_2 & cfl_3 & \cdots & \cdots & cfl_3
\end{pmatrix}_{(\tau'+2)\times 3\tau'}
$$

$$
\boldsymbol{B}_{\boldsymbol{\tau}'} = \begin{pmatrix}
1 & \cdots & \cdots & 1 & 0 & \cdots & \cdots & 0 & 0 & \cdots & \cdots & 0 \\
k_1 & & & & k_2 & & & & k_3 & & & \\
& \ddots & & & & \ddots & & & & \ddots & & \\
& & k_1 & 0 & & & k_2 & 0 & & & k_3 & 0 \\
0 & \cdots & \cdots & 0 & 1 & \cdots & \cdots & 1 & 0 & \cdots & \cdots & 0 \\
0 & \cdots & \cdots & 0 & 0 & \cdots & \cdots & 0 & 1 & \cdots & \cdots & 1
\end{pmatrix}_{(\tau'+2)\times 3\tau'}
$$

We define $\boldsymbol{M}_{\boldsymbol{\tau}'}$ and $\boldsymbol{B}_{\boldsymbol{\tau}'}$ to represent the input and output coefficient matrices of the accelerated depreciation without investment.

By observing Table 3 above, we can conclude that the matrix for accelerated depreciation differs from that of general depreciation, resulting in differences in both the model and the potential GDP growth rate. Compared to the benchmark model of general depreciation, Eqs. (28) and (31) extend the model while maintaining consistency in its fundamental objectives and methodology. Theoretically, both models aim to solve for equilibrium, thereby providing a long-term examination of macro-economic impacts. In terms of parameters, key factors such as production technology and the real wage rate are held constant after Okishio. However, to integrate accelerated depreciation, the structure and the elements of the matrix are jointly determined by the reduced years of accelerated depreciation and the inclusion or exclusion of new investment. Regarding results, both models facilitate the determination of the potential GDP growth rate as a function of τ', which serves as the theoretical foundation for constructing the "Depreciation-profit-growth" curve presented in the next section.

It is also important to note that, unlike the approach of Okishio and Nakatani (1975), which simplifies the non-square system into a Leontief framework with only new products, our Marx-Okishio approach maintains the non-square matrix

Table 3 Comparison between the general depreciation model and accelerated depreciation model

Depreciation	Equilibrium Equation	Solution: potential GDP growth rate	
General			
	$\boldsymbol{pB}_{\boldsymbol{\tau}} = (1 + r_\tau)\boldsymbol{pM}_{\boldsymbol{\tau}}$ (25)	$\lambda_\tau \boldsymbol{p} = \boldsymbol{pM}_{\boldsymbol{\tau}}\boldsymbol{B}_{\boldsymbol{\tau}}^{+}, \lambda_\tau = \frac{1}{1+r_\tau}$ (26)	$g_\tau = \alpha r_\tau$ (27)
Accelerated			
w/ Investment	$\boldsymbol{pB}_{\boldsymbol{\tau}}^{\tau'} = (1 + r_\tau^{\tau'})\boldsymbol{pM}_{\boldsymbol{\tau}}^{\tau'}$(28)	$\lambda_\tau^{\tau'} \boldsymbol{p} = \boldsymbol{pM}_{\boldsymbol{\tau}}^{\tau'} \boldsymbol{B}_{\boldsymbol{\tau}}^{\tau'+}, \lambda_\tau^{\tau'} = \frac{1}{1+r_\tau^{\tau'}}$(29)	$g_\tau^{\tau'} = \alpha r_\tau^{\tau'}$(30)
w/o Investment	$\boldsymbol{pB}_{\boldsymbol{\tau}'} = (1 + r_{\tau'})\boldsymbol{pM}_{\boldsymbol{\tau}'}$(31)	$\lambda_{\tau'} \boldsymbol{p} = \boldsymbol{pM}_{\boldsymbol{\tau}'} \boldsymbol{B}_{\boldsymbol{\tau}'}^{+}, \lambda_{\tau'} = \frac{1}{1+r_{\tau'}}$(32)	$g_{\tau'} = \alpha r_{\tau'}$(33)

structure even in the context of accelerated depreciation. This approach is more suitable for joint production scenarios that incorporate depreciated fixed capital.

5 Simulation of accelerated depreciation

This study simulates the accelerated depreciation in China. To this end, the study utilizes China's input-output data (1981–2020) to construct a structural table of three major sectors. The parameters k_1~k_3, a_1~a_3, f, and l_1~l_3 are calculated, as shown in Table 4. The basic logic of this approach is to consider the reproduction process to take place in abstract major sectors and, subsequently, distinguish between fixed capital, the general means of production, and the means of consumption.

In this simulation, the fixed capital input coefficient k_1~k_3 remains high and grows rapidly; however, the growth is slow in the case of the general means of production input coefficient a_1~a_3. As a result, the average depreciation period of fixed capital in abstract major sectors gradually expands. This change can also be explained by the rapid rise in the wage vector coefficient per unit labor f and the continuous decline in the labor input coefficient: l_1~l_3. Here, the labor input coefficients l_1~l_3 represent the labor required for expanding reproduction, serving as a measure of labor "consumption." When discussing the equilibrium accumulation trajectory, we do not consider excess or shortage of labor supply. There are two main possible explanations for their annual decline: one is the evolution of relations of production where capital substitutes for labor, particularly when the speed of capital accumulation exceeds the speed of labor force growth; the other

Table 4 Matrix parameters

	k_1	k_2	k_3	a_1	a_2	a_3	f	l_1	l_2	l_3
1981	0.8301	0.0277	0.0250	0.6514	0.5007	0.4968	0.3284	0.6462	0.9613	1.0115
1987	1.2811	0.0287	0.0125	0.6814	0.5450	0.5121	0.7222	0.2849	0.3978	0.4347
1990	1.2786	0.0232	0.0102	0.6954	0.5873	0.5319	0.8687	0.2184	0.2880	0.3272
1992	1.4035	0.0347	0.0123	0.6901	0.6185	0.5552	1.1272	0.1788	0.2072	0.2510
1995	1.4680	0.0336	0.0159	0.6967	0.6244	0.5672	2.5018	0.0747	0.0873	0.1034
1997	1.5047	0.0325	0.0124	0.6970	0.6265	0.5667	3.3636	0.0565	0.0645	0.0761
2000	1.6005	0.0341	0.0157	0.7221	0.6478	0.5793	4.3218	0.0408	0.0487	0.0603
2002	1.4352	0.0408	0.0163	0.7296	0.6185	0.5249	5.1490	0.0314	0.0436	0.0541
2005	1.6734	0.0461	0.0280	0.7113	0.6778	0.5545	5.4831	0.0278	0.0311	0.0428
2007	1.6881	0.0338	0.0278	0.7482	0.6892	0.5631	7.6883	0.0166	0.0200	0.0278
2010	1.7154	0.0476	0.0398	0.7231	0.7008	0.5385	11.1301	0.0123	0.0132	0.0198
2012	1.6608	0.0458	0.0338	0.7168	0.6856	0.5395	15.8003	0.0092	0.0101	0.0145
2015	1.7292	0.0406	0.0300	0.7338	0.6945	0.5395	19.9798	0.0072	0.0082	0.0121
2017	1.6667	0.0258	0.0298	0.7141	0.6453	0.5398	23.8474	0.0070	0.0079	0.0103
2018	1.6709	0.0262	0.0280	0.7197	0.6404	0.5253	26.5252	0.0061	0.0072	0.0096
2020	1.6474	0.0234	0.0232	0.7207	0.6335	0.5188	28.8608	0.0058	0.0069	0.0090

Author's calculations.

is the reduction in socially necessary labor time, typically a manifestation of technological progress. Nevertheless, the impact of accelerated depreciation on labor supply warrants further discussion. In this study, we consider it as a reflection of the current relations of production and technological level.

These parameters vary annually and are shaped by the specific economic structure of each year. In simulating accelerated depreciation for a given year, we hold these conditions constant. This approach allows us to isolate the impact of accelerated depreciation while maintaining the assumptions about fixed capital input coefficients and other parameters, as determined by the exogenous technical factors of that year.

For this simulation, we take the general depreciation as the control group. This study discusses the general depreciation by using the average value $\tau = 25$ of the time for the economic benefits, as generated by the fixed assets in various industries. Subsequently, we solve Eq. (25) to obtain the profit rate r_τ and the potential GDP growth rate g_τ of the general depreciation. The yellow curves in Figs. (3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18) show this result, which is compared to the relevant results for accelerated depreciation. The differences reveal the promotion and adjustment effects.

The positions and trends of the curves are similar, as shown in Figs. (3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18). In other words, despite using different input-output data from 1981 to 2020, the result remains the same.

The promotion effect on economic growth is always positive, while the adjustment effect on economic accounting is always negative; both become more significant with the shortening of the depreciation period. Therefore, the robustness and explanation of the above two models have been tested to some extent.

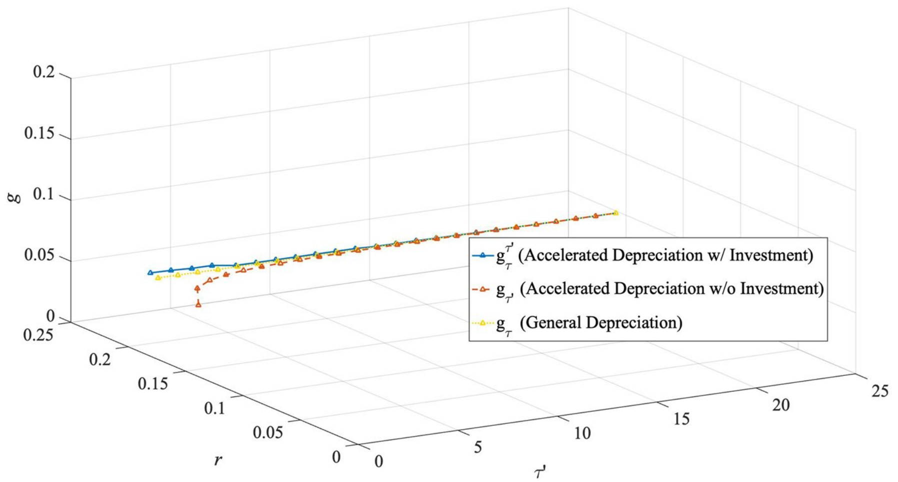

Fig. 3 Depreciation-profit-growth in 1981

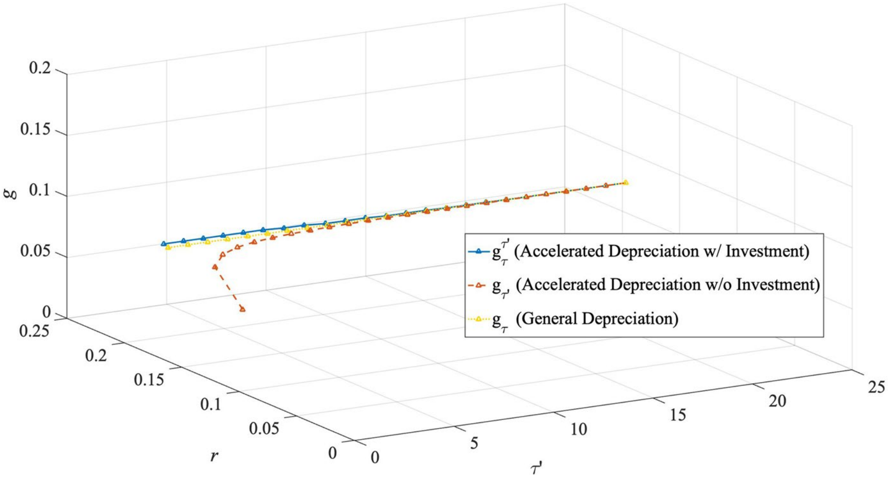

Fig. 4 Depreciation-profit-growth in 1987

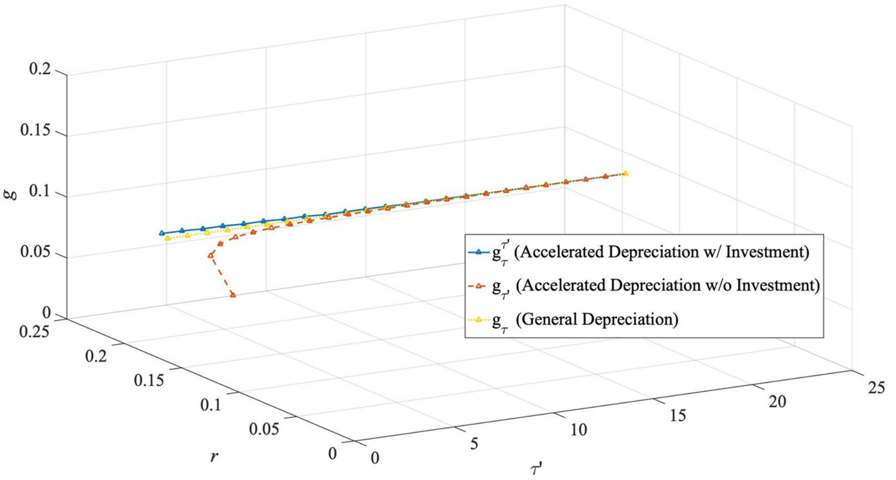

Fig. 5 Depreciation-profit-growth in 1990

5.1 Promotion effect

First, we solve Eq. (28)—the model of the accelerated depreciation including investment. Subsequently, we calculate the profit rate $r_\tau^{\tau'}$ and the potential GDP growth rate $g_\tau^{\tau\prime}$. The blue curves in Figs. (3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18) indicate the levels $r_\tau^{\tau'}$ and $g_\tau^{\tau'}$ and their change with the shortening of the accelerated depreciation period. These curves lie above the straight control line. As long as the depreciation period is shortened, the profit rate and potential GDP growth rate will be higher than that of the general depreciation. In other words, the accelerated depreciation always plays a positive role in promoting

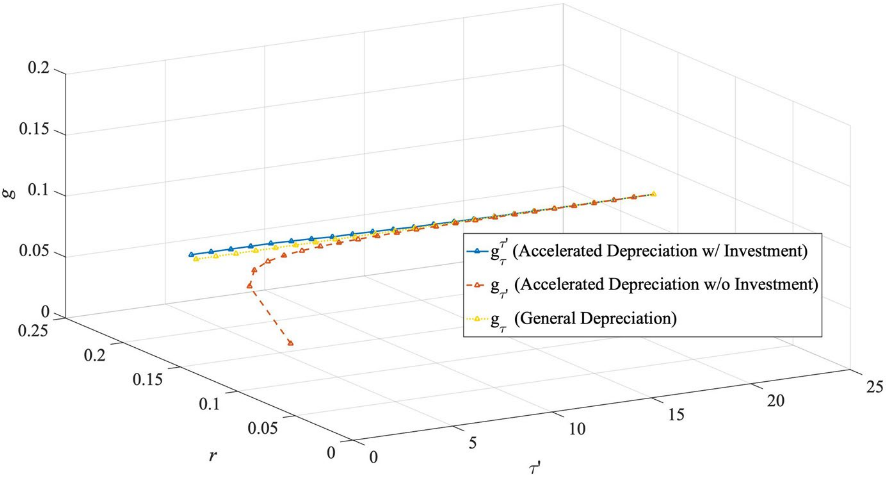

Fig. 6 Depreciation-profit-growth in 1992

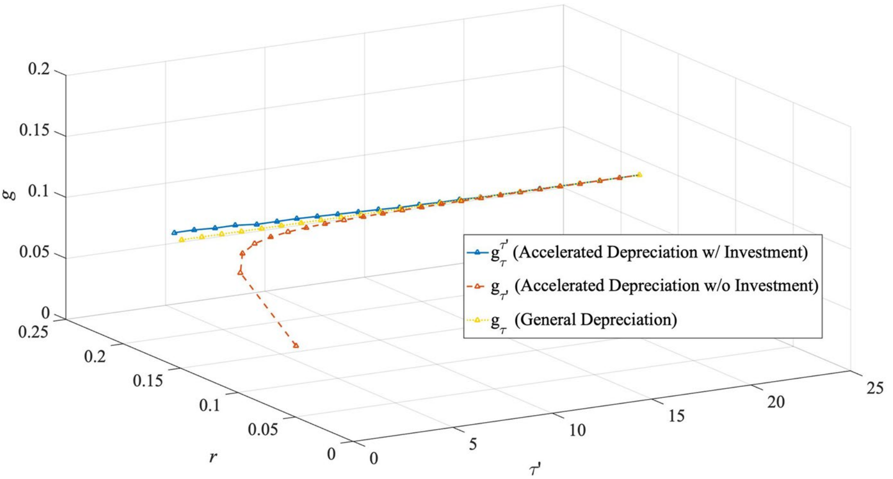

Fig. 7 Depreciation-profit-growth in 1995

economic growth as it can improve an enterprise's cash flow. If it is transformed into investment, where it positively influences reproduction, then, on the supply-side, industrial upgradation and technological progress will make a positive contribution to the long-term economic growth.

The difference between the curves and the straight control line characterizes the promotion effect of the accelerated depreciation on economic growth. The promotion effect correlates negatively with the accelerated depreciation period, which becomes more significant with the shortening of the depreciation period. When the degree of accelerated depreciation is large, there is a significant deviation of the average profit and potential GDP growth rates from the general

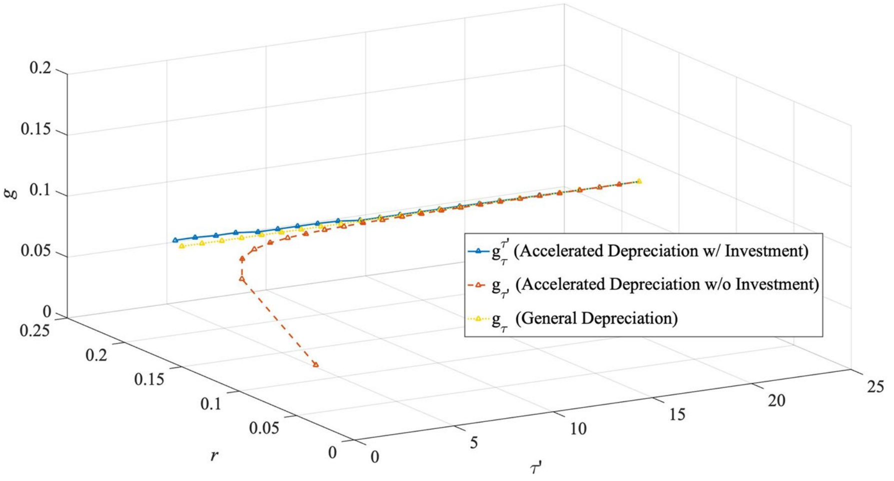

Fig. 8 Depreciation-profit-growth in 1997

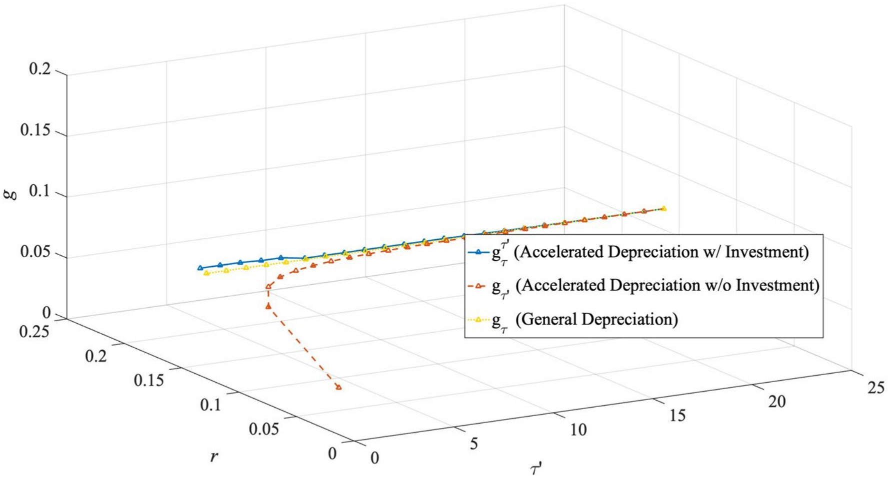

Fig. 9 Depreciation-profit-growth in 2000

depreciation. The intensity of tax incentives increases as the depreciation period is further shortened.

$P_{\tau\to\tau'} = g_\tau^{\tau'}/g_\tau - 1$ refers to the changing ratio of the potential GDP growth rate, which further quantifies the promotion effect. This result is reported in Table 5, providing evidence for both conclusions. First, $P_{\tau\to\tau'} > 0$ shows that the direction of the promotion effect is always positive. Second, $P_{\tau\to\tau'}$ is a decreasing function of τ', indicating that it becomes more significant as the accelerated depreciation period shortens. Another significant finding is that the promotion effect varies annually, even during the same accelerated depreciation period—different years mean different asset structures. China's economic trend from 1981

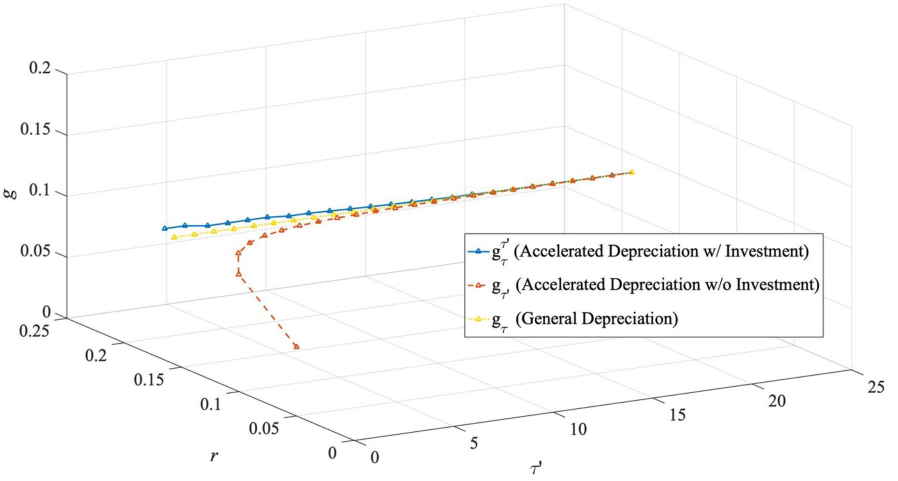

Fig. 10 Depreciation-profit-growth in 2002

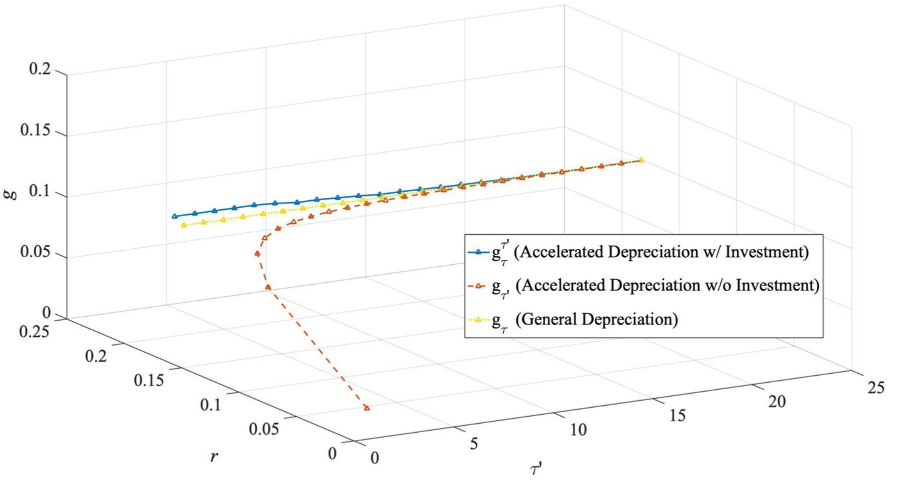

Fig. 11 Depreciation-profit-growth in 2005

to 2020 represents an extension of the average depreciation period. In general, the promotion effect is enhanced as the asset structure moves from the short- to long-term. It shows that the promotion effect is influenced by the asset structure of the abstract major sectors, which is limited in the short- but amplified in the long-term.

The literature has focused on the short-term tax incentives at the micro-level; to the best of our knowledge, this is the first study to examine the long-term impact of accelerated depreciation at the macro-level. This representative tax reduction policy can be evaluated in relation to China. In fact, the choice of accelerated depreciation periods, as listed in Table 5, have important practical significance.

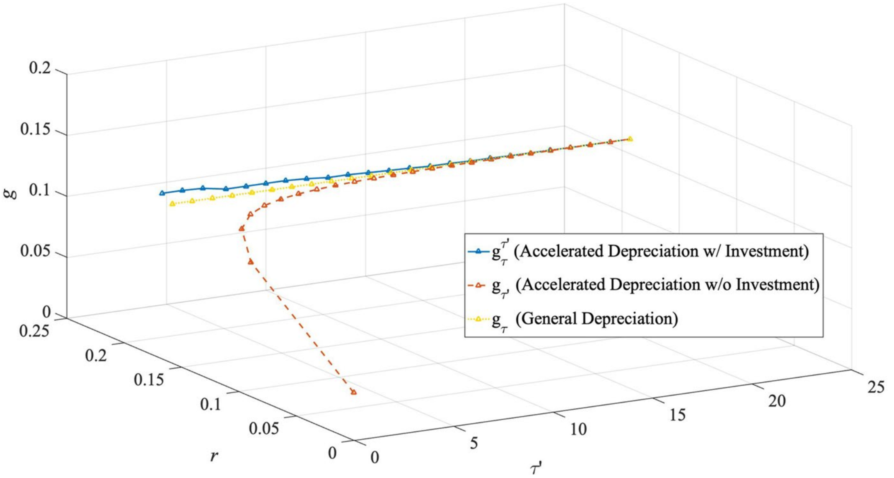

Fig. 12 Depreciation-profit-growth in 2007

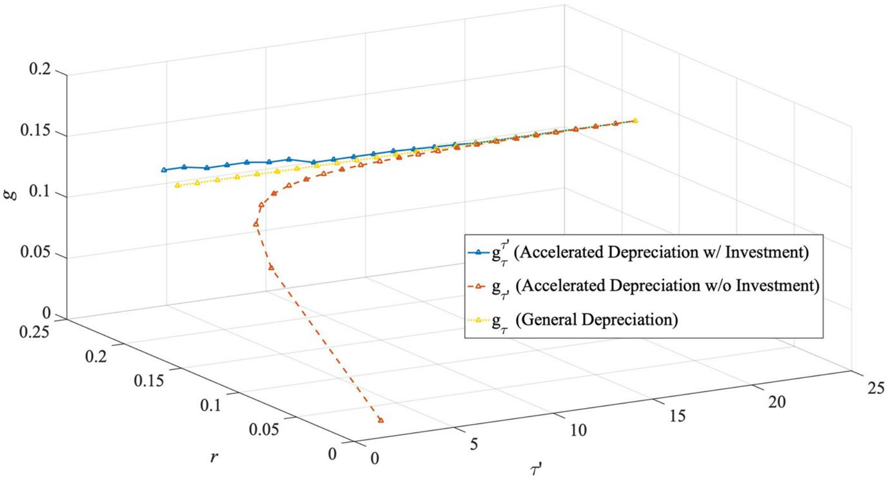

Fig. 13 Depreciation-profit-growth in 2010

Before the issuance of *The Notice* (2014), when the service age was high, the general depreciation period could also be shortened according to *The Regulations*; the promotion effect existed to a less extent. Considering that the asset structure of the abstract major sectors is relatively long-term, we take the maximum of the minimum depreciation period $\tau' = 20$, to test the contribution of *The Regulations*. The mean is 0.06%, which is not significant. Then, $\tau' = 12$ is taken to correspond to the accelerated depreciation period according, to *The Notice* (2014). The mean is 0.93%, which is more significant. Furthermore, we calculate the contribution of *The Notice* without the influence of *The Regulations*; the mean is 0.87%. This result confirms that the promotion effect of the accelerated depreciation on economic growth

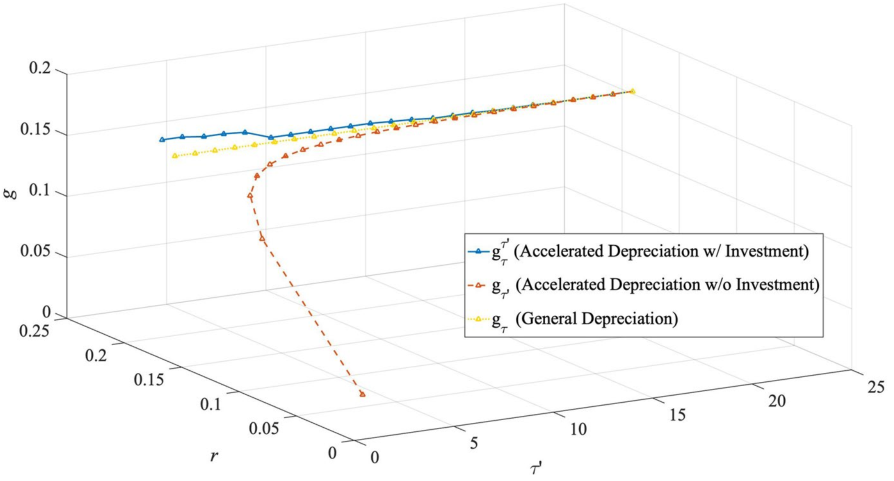

Fig. 14 Depreciation-profit-growth in 2012

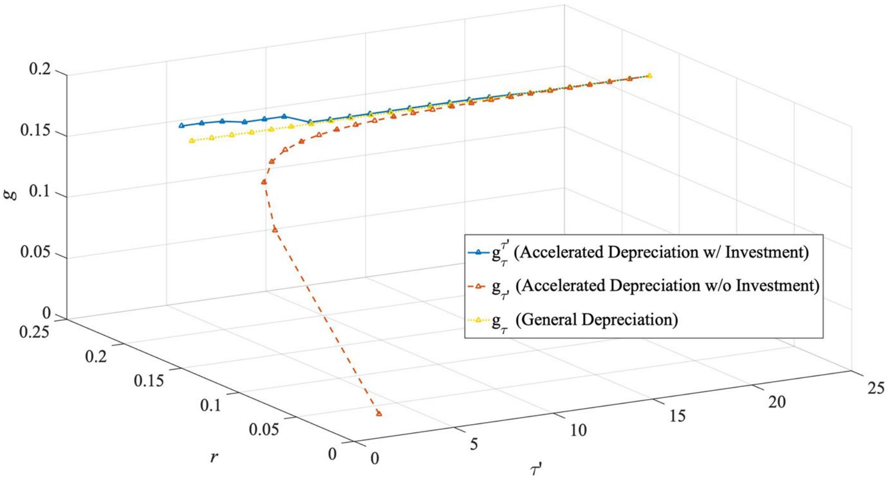

Fig. 15 Depreciation-profit-growth in 2015

is mainly attributed to *The Notice* (2014). In addition, under the condition that the tax incentives are converted into investment, the accelerated depreciation provides a 0.87% scope for improvement in the potential GDP growth rate. Thus, the tax reduction policy can be used as an effective tool for macroeconomic regulations in China.

After the release of *The Notice* (2014), there is a change in the promotion effect, which is worthy of attention. Since 2015, there is a deceleration in the contribution of the slightly accelerated depreciation ($\tau' = 20$ and $\tau' = 12$). We find a gain in the intensity of the impact when $\tau' = 8$ and $\tau' = 4$ are used to locate where the degree of accelerated depreciation is greater. This is because, in pilot industries such as biopharmaceutical and electronic manufacturing, the fixed assets, in

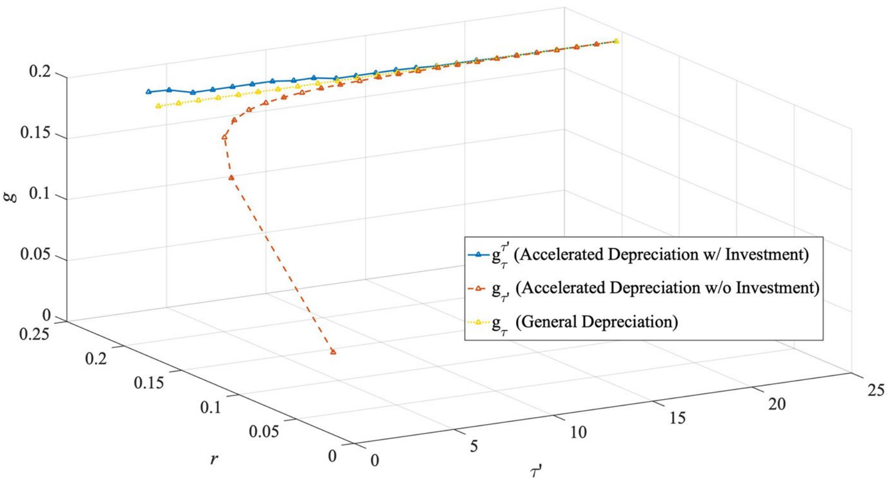

Fig. 16 Depreciation-profit-growth in 2017

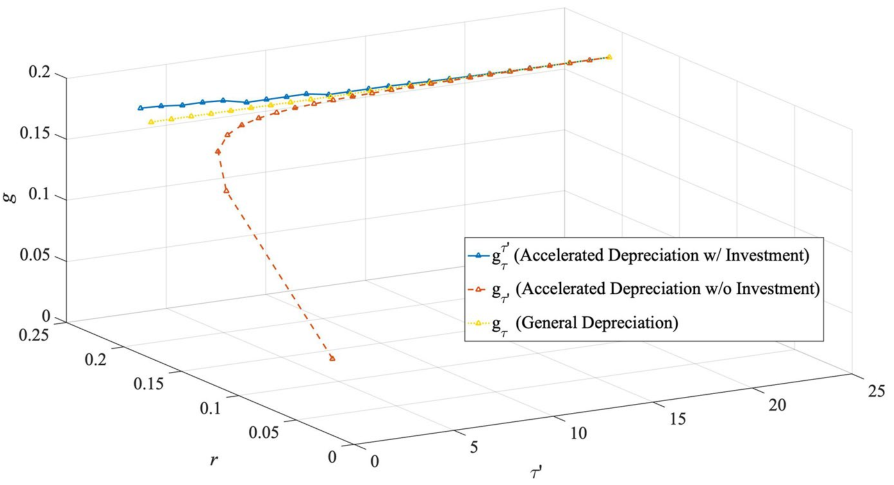

Fig. 17 Depreciation-profit-growth in 2018

the state of either strong vibration or high corrosion, are rapidly updated; these assets account for a large proportion of the total and have a short actual service age. The above industries implemented accelerated depreciation in 2014; hence, slightly accelerated depreciation does not hold significance. In this context, the results suggest the criticality of *The Notice* (2014). On the one hand, the pilot of accelerated depreciation is timely and opportune, rapidly promoting supply-side industrial upgradation and technological progress. On the other hand, accelerated depreciation gradually covers the fixed assets with an actual service age. The

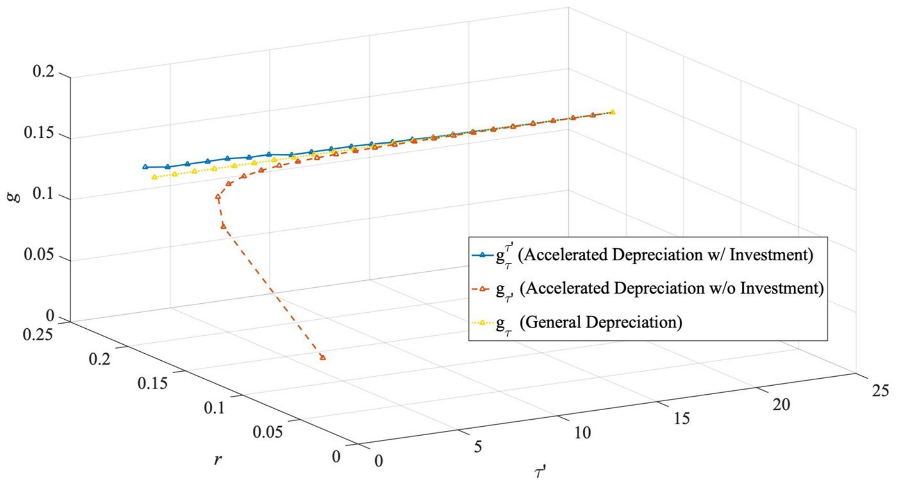

Fig. 18 Depreciation-profit-growth in 2020

Table 5 Promotion effect $P_{\tau\rightarrow\tau'}$ in China (1981–2020)

	Under *Regulations*	Under *Notice*	The Degree is Greater	
	$\tau' = 20$ (%)	$\tau' = 12$ (%)	$\tau' = 8$ (%)	$\tau' = 4$ (%)
1981	0.05	0.73	0.73	2.45
1987	0.02	0.79	1.44	1.95
1990	0.05	0.66	1.20	2.03
1992	0.02	0.96	1.96	2.51
1995	0.05	1.03	2.14	3.06
1997	0.07	0.33	1.67	2.76
2000	0.05	0.67	0.67	3.24
2002	0.05	1.21	2.20	2.97
2005	0.12	1.25	2.81	4.23
2007	0.09	1.31	2.75	4.27
2010	0.08	1.40	3.72	4.81
2012	0.12	1.64	1.64	4.98
2015	0.02	0.52	0.52	4.65
2017	0.02	0.67	2.40	2.40
2018	0.04	0.68	1.75	3.54
2020	0.06	1.00	2.16	2.80
Mean	0.06	0.93	1.86	3.29

Author's calculations.

Government Work Report (2019) extended it to include all the manufacturing sectors, given that the tax reduction policy is becoming more comprehensive, highly preferential, and critical at a macro-level.

5.2 Adjustment effect

Second, we solve Eq. (31)—the model of accelerated depreciation without investment. We calculate the profit rate $r_{\tau'}$ and the potential GDP growth rate $g_{\tau'}$. The result of this estimation is presented through the red curves in Figs. (3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18)—we identify the levels of $r_{\tau'}$ and $g_{\tau'}$, as their accelerated depreciation period shortens.

Unlike the promotion effect, we find that this curve is above the straight control line. As long as the depreciation period is shortened, the profit and potential GDP growth rates will be lower than that of the general depreciation. Tax incentives come from the loss of profit, and hence the adjustment effect always plays a negative role in economic accounting. This finding highlights the need for the investment effect for stimulating the promotion effect; otherwise, a cash flow improvement would fail to strengthen economic growth through investment.

Similar to the promotion effect, the difference between the curve and the straight control line characterizes the adjustment effect of the accelerated depreciation on economic accounting. The adjustment effect is positively correlated with the accelerated depreciation period, becoming more significant as it shortens. The greater the degree of the accelerated depreciation, the greater the subsequent one-time deduction and thus the more serious the impact on the long-term economic accounting.

$A_{\tau\to\tau'} = g_{\tau'}/g_{\tau} - 1$ refers to the change ratio of the potential GDP growth rate; this expression further quantifies the adjustment effect, as is reported in Table 6,

Table 6 Adjustment effect $A_{\tau\to\tau'}$ in China (1981-2020)

	Under *Regulations*	Under *Notice*	The Degree is Greater	
	$\tau' = 20$ (%)	$\tau' = 12$ (%)	$\tau' = 8$ (%)	$\tau' = 4$ (%)
1981	−0.07	−0.51	−1.36	−4.95
1987	−0.09	−0.63	−1.67	−6.65
1990	−0.07	−0.52	−1.40	−5.58
1992	−0.14	−0.95	−2.42	−9.40
1995	−0.13	−0.92	−2.42	−9.82
1997	−0.12	−0.85	−2.25	−9.60
2000	−0.18	−1.14	−2.91	−11.78
2002	−0.14	−1.02	−2.71	−10.98
2005	−0.20	−1.44	−3.82	−16.10
2007	−0.15	−1.11	−3.02	−13.33
2010	−0.22	−1.55	−4.16	−17.83
2012	−0.19	−1.41	−3.79	−16.14
2015	−0.21	−1.43	−3.77	−16.06
2017	−0.11	−0.87	−2.42	−11.07
2018	−0.11	−0.84	−2.39	−11.10
2020	−0.09	−0.74	−2.09	−9.72
Mean	−0.14	−0.99	−2.66	−11.26

Author's calculations.

thus providing evidence for both conclusions. First, $A_{\tau\to\tau'} < 0$ shows that the direction of the adjustment effect is always negative. Second, $A_{\tau\to\tau'}$ is an increasing function of τ', indicating that it becomes more significant with the shortening of the accelerated depreciation period. Similar to the promotion effect, the adjustment effect of the accelerated depreciation on economic accounting is mainly attributed to *The Notice* (2014). Unlike the promotion effect, the recovery in 2015 can be seen as the effect of the pilot scheme on accelerated depreciation. However, there is no way to distinguish between the different actual service ages.

5.3 Investment effect

In this section, we explain the difference between the above two models. Considering the impact of the accelerated depreciation at the macro-level, the promotion effect is regarded as the optimal performance, while the adjustment effect corresponds to the worst possibility. By definition, the difference between the promotion and adjustment effects can then be obtained as follows:

$$P_{\tau\to\tau\prime} - A_{\tau\to\tau\prime} = \left(\frac{g_{\tau}^{\tau\prime}}{g_{\tau}} - 1\right) - \left(\frac{g_{\tau\prime}}{g_{\tau}} - 1\right) = \frac{g_{\tau}^{\tau\prime} - g_{\tau\prime}}{g_{\tau}} \tag{28}$$

The denominator derives from the equilibrium of the general depreciation, and the two numerators are the equilibriums of the accelerated depreciation. Clearly, the difference between the promotion and adjustment effects can be attributed to investment.

In Figs. (3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18), the difference between the two curves depicts the investment effect, which is always positive and becomes more significant with the shortening of the depreciation period. $I_{\tau\to\tau\prime} = (g_{\tau}^{\tau\prime} - g_{\tau\prime})/g_{\tau} - 1$ refers to the change ratio of the potential GDP growth rate, further quantifying the investment effect. This result is reported in Table 7, which provides evidence for both conclusions. First, $I_{\tau\to\tau'} > 0$ shows that the direction of the investment effect is always positive. Second, $I_{\tau\to\tau'}$ is a decreasing function of τ', indicating that it becomes more significant with the shortening of the accelerated depreciation period. The investment effect is enhanced as the asset structure moves from the short- term to long-term even over the same accelerated depreciation period. This result suggests that economic growth is becoming more investment-driven in China.

Considering the adjustment effect, the investment drive is a necessity, but not a sufficient condition for the promotion effect. If the promotion effect exists, then the investment effect must exist and compensate for the adjustment effect, meaning that $I_{\tau\to\tau\prime} > P_{\tau\to\tau\prime}$. However, the contribution of the positive investment effect may be less than that of the negative adjustment effect, making it impossible to observe the promotion effect. In other words, the investment effect is the source of the promotion effect, and the promotion effect is the embodiment of the investment effect. It cannot be ignored that there is an adjustment effect between them.

Table 7 Investment effect $I_{\tau \to \tau'}$ in China (1981–2020)

	Under *Regulations*	Under *Notice*	The Degree is Greater	
	$\tau' = 20$ (%)	$\tau' = 12$ (%)	$\tau' = 8$ (%)	$\tau' = 4$ (%)
1981	0.11	1.24	2.09	7.40
1987	0.10	1.41	3.11	8.59
1990	0.12	1.18	2.60	7.61
1992	0.17	1.91	4.38	11.91
1995	0.18	1.95	4.56	12.88
1997	0.19	1.17	3.92	12.36
2000	0.23	1.81	3.58	15.02
2002	0.19	2.23	4.91	13.94
2005	0.32	2.69	6.63	20.33
2007	0.25	2.42	5.77	17.60
2010	0.29	2.95	7.88	22.64
2012	0.31	3.05	5.44	21.12
2015	0.23	1.96	4.30	20.71
2017	0.14	1.54	4.82	13.47
2018	0.15	1.52	4.14	14.64
2020	0.16	1.73	4.25	12.52
Mean	0.20	1.92	4.52	14.55

Author's calculations.

6 Conclusions and prospects

This study has examined whether the tax reduction policy represented by accelerated depreciation can promote economic growth. This study has four major contributions. First, we innovated the Marx-Okishio perspective and method of systematic research on the accelerated depreciation, dividing the promotion effect into negative adjustment and positive investment effects, both of which become more significant with the shortening of the depreciation period; the theory clarifies that the investment effect is a necessary but insufficient condition for the promotion effect. Second, we constructed a three-sectoral reproduction model of the fixed capital depreciation and extended it to simulate how the accelerated depreciation could affect the economic growth. Third, we considered China's income tax reform; the policy and relevant theoretical explanations are unique. The existing literature either focuses on the USA and other developed countries or on the value-added tax reduction; this study supplements the literature. Fourth, we used the model and the input-output data from China to draw the "depreciation-profit-growth" curve from 1981 to 2020. By examining the promotion effect on economic growth and quantifying it, we evaluated the long-term impact of accelerated depreciation policy on the macro-level performance of the China's economy.

Nevertheless, this study only considered the average of the actual service age of all industries, without fully considering their individual situations. Therefore, further studies are needed to draw more specific conclusions. Additionally, while this study highlighted the negative adjustment effect caused by shortening the depreciation period due to increased costs, further research is necessary to explore its characteristics in greater depth. Specifically, its degree and rate of change over time deserve investigation to determine whether it exhibits particular patterns. Understanding these patterns and their economic significance could offer new insights into the policy applicability across various contexts.

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