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# Catch-Up Industrial Policy and Economic Transition in China*

Justin Yifu Lin† Wei Wang‡ Venite Zhaoyang Xu§

February 23, 2020

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This paper studies how catch-up industrial policies in China affect economic development in a two-sector neoclassical growth model. To fulfill their aspirations of catching up with the output of the capital-intensive sector of developed countries, Chinese political leaders adopted industrial policies that subsidize this target sector at the expense of other sectors from 1952 until the economic reform in 1978. The static effect of this industrial policy distorts the allocation of resources across sectors and lowers the aggregate TFP. The dynamic effect discourages the accumulation of capital. We show that although the output of the capital-intensive sector boosts initially, it will be lower than its first-best counterpart in the long run if catch-up aspirations are too strong. Our theoretical predictions are consistent with the experience of the Chinese economy from 1952 to 1978.

**Keywords**: Catch-up industrial policy; Misallocation; Ramsey allocation problem; Economic development.

**JEL Codes**: O11; O23; O25; O41; E62



*We are grateful to Jinhui Bai, Paco Buera, Oded Galor, Liutang Gong, Ann Harrison, Roberto Samaniego, Yongs Shin, Lixue Wu and all participants of the 2012 and 2015 International Conference on New Structural Economics for helpful comments. Wei Wang and Venite Xu would like to thank the National Natural Science Foundation of China (Grant No. 71703017 and 71573039, respectively) for financial support.

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# 1 Introduction

The first generation of political leaders of the People's Republic of China adopted a preferential policy for promoting capital-intensive (heavy) industries from 1952 to 1978 (the pre-reform period). However, this policy is unsuccessful at all.[1] In this paper, we argue that the catch-up aspiration of the first generation of Chinese political leaders are important reasons why such industrial policy is adopted. The main goal of this paper is to investigate how the industrial policy implied by the catch-up aspiration affects sectoral resource misallocation and economic growth. We find that the catch-up industrial policy causes resource misallocation and lowers measured aggregate TFP. Therefore, although output of the capital-intensive sector booms initially, it will be lower than its first-best counterpart in the long run if the catch-up aspiration is too strong. Our results are consistent with the experience of the Chinese economy during this pre-reform period.

Capital-intensive/heavy industries were chosen by the first generation of Chinese political leaders as target industries to promote the output of these industries to the extent that was obviously unproportionate to their income levels.[2] Industrial policies can be very effective in promoting growth. Rodrik (2004) argues that properly formulated industrial policies have an important role to play in promoting growth. Aghion et al. (2015) show that industrial policies that foster competition could increase productivity growth. However, if industrial policies are not well designed, as the industrial policy adopted in pre-reform China, they could lead to resource misallocation and lower growth rates.[3]

An interesting question is that why did China adopt the industrial policy that targets capital-intensive/heavy industries? A standard view believes that Chinese political leaders were mainly influenced by some interventionism theories and then decided to adopt corresponding policies (Krueger, 1997).[4] However, this view is not quite convincing in China. On the one hand, it was politically unacceptable to propagate western economic theories. So, we can hardly imagine that political leaders in China were influenced by the above arguments. On the other hand, industrial

[1] For example, during the entire period of 1952-1978, the GDP difference between China and US remained 12-fold.

[2] This also happens in other socialist countries. For example, in 1970, PPP-adjusted GDP per capita of Hungary, Poland and Romania was roughly one third, one fifth and one eighth of that of the United States, but their crude steel output per capita are 53 percent, 63 percent and 56 percent of that of the United States, respectively. As an extreme example, in 1970, North Korea's GDP per capita was simply 2.3 percent of that of the United States, but surprisingly North Korea produced 28 percent of the crude steel output per capita of the United States. GDP data are from Feenstra, Inklaar and Timmer (2015). Crude steel output data are from Department of Economic and Social Affairs, Statistical Office of the United Nations, Industrial Commodity Statistics Yearbook 1975.

[3] For example, Rodrik (2004) points out that public support must target activities instead of sectors. The World Bank (2008) argues that industrial policy should be agnostic about particular industries, leaving the remainder of the choice to private investors as much as possible. Moreover, Harrison and Rodriguez-Clare (2010) find little support for industrial policies that are "hard" interventions.

[4] Most of these theories can be classified into three categories: structuralism, externality and imperfect competition. Structuralism emphasizes income growth due to structural movement of labor and capital from traditional sectors to modern sectors (Lewis, 1954; Chenery, 1958, 1960, 1975; Kuznets, 1966). Externality theory suggests that government policies should favor industries or activities that yield externality (Hirschman, 1958; Baldwin, 1969; Greenwald and Stiglitz, 2006; Nunn and Trefler, 2010). Imperfect competition theory argues that government policies can tilt the terms of oligopolistic competition to shift excess returns from foreign to domestic firms (Brander and Spencer, 1983, 1985).

policies were deeply influenced by the USSR's experience. These policies were actually formulated in the 1930's before the interventionism theories began to prevail.

In fact, the catch-up industrial policy was more related to the trend of nationalism after World War II. The popularity of nationalism could be traced back to the end of World War I and it deeply affected the thoughts of most political and social elites in China and many other socialist countries. Under the influence of nationalism, Chinese political leaders believed that their nations should give the first priority to the enhancement of their political and military power as well as international status as soon as possible in order to survive in a world ruled by the jungle law. Catching-up with developed countries, in terms of the output of capital-intensive/heavy industries, was considered as the milestone of achieving this goal. Consequently, all kinds of distortionary policies to stimulate these industries were introduced. We name this kind of preference of political leaders as catch-up aspirations and will describe in detail in Section 2.

Political leaders in China design policies or establish institutions primarily based on goals of themselves, their personal aspirations or even their own biases (Eicher and Garcia-Penalose, 2006; Acemoglu et al., 2008a,b).[5] As Rodrik (2014) argued, explicitly modeling the ideas and the resulting preferences of politicians is necessary when it comes to policy choices. Our paper develops a two-sector neoclassical growth model in which there is a government or politician who gains utility from not only the social welfare, but also his/her own aspirations of catching up with developed countries in terms of the output of capital-intensive industries.[6] Specifically, the preference of the government in our model is a combination of the catching-up-with-the- Joneses preference and the social-status preference.[7] This assumption is obviously different from the literature on economic growth and development which always assumes the government to be benevolent, devoting itself to maximizing the social welfare.

The assumption about the preference of the politician is crucial for our paper. With catch-up aspirations, the politician has incentive to use his/her discretionary power to create a policy framework for allocating resources to the prioritized capital-intensive sector similar to that of developed countries. In particular, the government taxes the labor-intensive sector to subsidize the capital-intensive sector. We name these taxes/subsidies (wedges) the catch-up industrial policy. The optimal catch-up industrial policy is derived by solving the Ramsey allocation problem of the government (Chamley, 1986; Judd, 1985). In this framework, the representative household and firms make their decisions taking the government's policies as given. The government then chooses industry policies to maximize its own utility.[8]

[5]Recently, a fast growing literature argues institutions are fundamental for economic growth. See (Acemoglu et al., 2001, 2002; Acemoglu and Robinson, 2000, 2001; Eicher and Garcia-Penalose, 2008).

[6]We use the government and the politician interchangeably.

[7]The catching-up-with-the-Joneses models use preferences that happiness depends at least in part on the comparison of one's own consumption to that of the others (Abel, 1990, 1999). The "social status" models argue that investors accumulate wealth for the sake of not only consumption but also the wealth-induced social status (Cole et al., 1992; Zou, 1994).

[8]Recently, Acemoglu et al. (2008c), Acemoglu et al. (2010) and Acemoglu et al. (2011) discussed the optimal fiscal policies in the framework of the Ramsey allocation problem of the non-benevolent government. Our paper mainly

In the Ramsey allocation problem, the government has to balance the static and dynamic effects of the catch-up industrial policy. The immediate (static) effect of an increase of tax/subsidy is that the output of the capital-intensive sector jumps up. However, the aggregate TFP is smaller due to the misallocation of resources across the two sectors, resulting from the distortionary industrial policy. This effect lowers the final output and we show that the marginal return of capital is smaller as well because of the lower TFP. Consequently, lower output discourages the accumulation of capital and eventually the final output declines in the long run.

We show that if the degree of catch-up aspirations of the government is higher, the government will choose higher tax/subsidy rate. Ultimately, the final output would be lower than its first-best counterpart in the long run, although the output of capital-intensive goods might be larger. If the policy is too distortionary (very high tax/subsidy rate), the output of the capital-intensive sector might be lower than its first-best counterpart in the long run as well. These results are consistent with stylized facts of China and many other developing countries that adopted the catch-up industrial policies. Recently, Jaimovich and Rebelo (2017) also study how growth is affected by distortionary taxes that reduce private incentives to invest.

**Related Literature** Our paper mainly relates to four strands of literature. Firstly, our paper joins a growing literature of multi-sector growth and structural change models. Our model is developed based upon several multi-sector growth models (Galor, 1992; Eicher and Turnovsky, 1999a; Kongsamut et al., 2001; Ngai and Pissarides, 2007; Acemoglu and Guerrieri, 2008)[9]. Galor (1992) fully characterized the dynamical system of a two-sector (consumption and investment) overlapping-generation model. Eicher and Turnovsky (1999a) developed a general two-sector growth model. We consider an infinite-horizon growth model, instead of an overlapping-generation model, with the capital- and labor-intensive sector. Our model is essentially a variant of the Acemoglu and Guerrieri (2008) modified to capture catch-up aspirations of politicians and the corresponding industrial policy.

The second strand is the literature on macroeconomic consequences of resources misallocation at the microeconomic level (Restuccia and Rogerson, 2008; Hsieh and Klenow, 2009; Buera, Kaboski and Shin, 2011; Buera and Shin, 2011, 2013; Jovanovic, 2014). Most, if not all, studies in this strand of literature focus on the misallocation of resources at the firm/plant level. Our paper highlights the misallocation at the sector level. The industrial policy in our model is distortionary, leading to the misallocation of resources between the two sectors. One of our main contributions is to investigate the effect of this industrial policy and the resulting misallocation of resources on macroeconomic variables at the sector and aggregate level.

focuses on the government's behavior and industrial policy and thus omits political process between the government and voters.

[9]More recent development of this literature includes Eicher and Turnovsky (1999b), Eicher and Turnovsky (2001) Buera and Kaboski (2009), Buera and Kaboski (2012), Buera, Kaboski and Rogerson (2015), Lin et al. (2015), among others. See Herrendorf et al. (2014) for a comprehensive discussion of the recent development of the structural transformation.

Our paper also relates to the literature on macroeconomic implications of industrial policies. Acemoglu et al. (2018) model industrial policies as exogenous subsidies/taxes on fixed operating costs and investigate the implications of these industrial policies in a model of misallocation and innovation with entry and exit of heterogeneous firms. The industrial policies in our model are also subsidies/taxes, but are endogenously determined in the Ramsey problem of the government. Aghion et al. (2015) show that only industrial policies that foster competition could increase productivity growth.

Last but not the least, our paper is also related to the literature on economic development and growth of the Chinese economy. The majority of this strand of literature focuses on the post-reform period. For example, Brandt, Hsieh and Zhu (2008), Brandt and Zhu (2010), and Dekel and Vandenbroucke (2012) conducted quantitative analysis of structural change and sectoral growth of the post-reform Chinese economy. Song et al. (2011) examined the role of financial frictions to justify the features of China's economic transition in the last three decades. Brandt, Tombe and Zhu (2013) and Tombe and Zhu (2015) investigated factor wedges across provinces and sectors in China after 1978. However, studies of the pre-reform Chinese macroeconomy is rare. One exception is Cheremukhin et al. (2015), who develop a quantitative two-sector neoclassical growth model with exogenous sectoral wedges. They find that the sectoral labor wedge and TFP growth are the most important factors that account for GDP growth and structural change in pre-reform China.[10]

Our paper differs from Cheremukhin et al. (2015) mainly in three aspects. First, they investigate how sectoral wedges accounts for GDP growth and structural transformation in pre-reform China quantitatively. We study how the catch-up industrial policy (sectoral wedges) affects the pre-reform Chinese economy in a theoretical model. Second, although both papers consider sectoral wedges as the driving force, the sectoral wedges are exogenous in Cheremukhin et al. (2015) yet endogenous in our model. Hence, the results of our model are not subjec to the Lucas critique.[11] Third, Cheremukhin et al. (2015) only consider the static effect of sectoral wedges in their counterfactual simulations and find that the capital wedge is quantitatively not important. In contrast, the sectoral wedge in our model affects resource misallocation in the short run and capital accumulation in the long run, which captures the static and dynamic effect respectively. We find the sectoral wedge is an important factor for economic performance in pre-reform China.[12] In a revised version, Cheremukhin et al. (2017) find that the capital wedge is as important as the labor wedge if the dynamic effect is taken into account.[13] In sum, the two papers adopt different approaches but derive similar results. Therefore, our paper and theirs are complementary to each other.

The remainder of this paper is organized as follows. Section 2 describes catch-up aspirations of the first generation of Chinese political leaders. Section 3 documents motivating stylized facts

[10]They also study the Chinese economy after the reform.

[11]Since exogenous wedges are not "deep parameters", the counterfactual experiments in Cheremukhin et al. (2015) are subject to the Lucas critique.

[12]We only consider the capital wedge in our baseline model for simplicity. We show that our model with both labor and capital wedges is isomorphic to the baseline model.

[13]Cheremukhin et al. (2017) develops a new method to derive the dynamic effect.

about the catch-up industrial policy during 1952-1978 in China. Section 4 describes the model and characterizes the competitive equilibrium and the Ramsey equilibrium at the steady state. Theoretical and numerical analyses of transitional dynamics are conducted in Section 5. Section 6 concludes. Appendix A describes the data and the framework that we use to construct our measure of the catch-up industrial policy. Appendix B consists of proofs. Appendix C considers an alternative industrial policy. Appendix D presents and analyzes a discrete-time version of the model in Section 4.

## 2 Catch-Up Aspirations and Industrial Policy in China

From the point of view of most political and social elites of China, lack of industrialization, especially the possession of large capital-intensive industries, which were the basis of military strength, political and economic power, was considered as the main reason why China had been backward, poor and weak. Having advanced capital-intensive industries, therefore, was considered as a major symbol of being a developed and politically powerful country. Hence, the elites adopted an ideology of economic nationalism and prioritized the development of capital-intensive industries in their countries after they gained political power from colonial rules (Lal and Myint, 1996; Lin et al., 1994; Lin, 2003, 2009).

China's political leaders had a strong catch-up aspirations for the development of modern industry. Mao Zedong proclaimed, before coming to power, that "without industry there can be no solid national defense, no well-being for the people, no prosperity and strength for the nation" (Mao, 1945). Zhou Enlai, a close associate of Mao, quoted Mao in (Zhou, 1953):

> Chairman Mao once said: our nation has obtained political independence, but if our nation wants to achieve complete independence, accomplishing industrialization is necessary. If industries are not developed, a country may become other countries' vassal even after the country has become independence. As a socialist country, can we have a dependence mentality? For example, let the Soviet Union develop heavy industries and national defense industries and let our nation develop light industries. Can we do that? In my opinion, we can not do that.

The Communist Party of China won the civil war and founded the People's Republic of China in 1949. After three years of recovering from the war, China started its first Five-Year Plan in 1953. The main objective was a high rate of economic growth, with primary emphasis on industrialization through the development of the capital-intensive sector even though at the expense of light industry and agriculture (CPC, 1955). In 1957, Mao further set up a specific goal: catching up with the Great Britain in 10 years and the United States in 15 years in terms of heavy industry output (Ashton et al., 1984). This is the starting point of the Great Leap Forward (GLF) in 1957-1960.

# 3 Catch-Up Industrial Policy

In this section , we document motivating stylized facts about the catch-up industrial policy during 1952-1978 in China. The main strategy of the First Five-Year Plan of China (1953-1957) is overwhelmingly allocating resources to capital-intensive industries (Lardy, 1987). During the GLF, a big push towards industrialization takes place. Despite the disastrous results due to the GLF, the Chinese government continues the catch-up industrial policy with only minor adjustment in magnitude until 1978.[14]

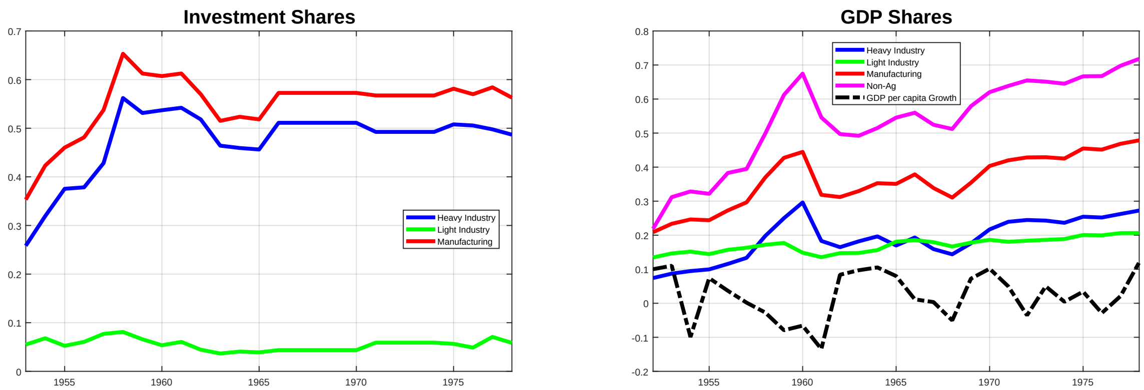


Figure 1: Investment and GDP Shares/Growth of Industry

Figure 1 presents the investment shares and GDP shares of the capital-intensive sector and light industry in this period. We use three definitions of the capital-intensive sector, i.e. heavy industry, manufacturing, and non-agriculture.[15] First, the investment share of the capital-intensive sector rises rapidly before 1960, declines in the next five years, and stays at a high level afterwards. The GDP share of capital-intensive sector evolves similarly over time except that it increases mildly after the plummet during 1961-1963.[16] In contrast, light industry is negligible in terms of both shares. Second, the GDP share of the capital-intensive sector is negatively correlated to the growth rate of GDP per capita, especially around the GLF. These facts suggest that the catch-up industrial policy that heavily invests in the capital-intensive sector is not growth-enhancing.

To implement the catch-up industrial policy, the Chinese government manipulates prices and wages, effectively subsidizing the capital-intensive industries while imposing heavy taxes on the other sector (Imai, 2000; Zhu, 2012). Documenting facts using direct measure of the industrial policy is challenging because the sectoral tax/subsidy data are not available. We adopt the method developed by Hsieh and Klenow (2009) and use the relative sectoral wedge as our measure of the catch-up

[14] See Cheremukhin et al. (2015) and the reference therein for a detailed description of the economic policies during this period.

[15] Heavy industry includes steel, machinery, and chemical industry, etc.

[16] The investment share of both heavy industry and manufacturing increases by 30 percentage points during 1952-1958. The GDP share increases by 25 percentage points in heavy industry and manufacturing and 45 percentage points in non-agriculture during 1952-1960.

industrial policy. In particular, the relative sectoral wedge is defined as the (inverse) ratio of the sectoral wedge of the capital-intensive sector and the other sector. Thus, a higher relative wedge means a stronger industrial policy that favors the capital-intensive sector. A detailed description of the data and the framework that we use to derive the measure is in Appendix A.

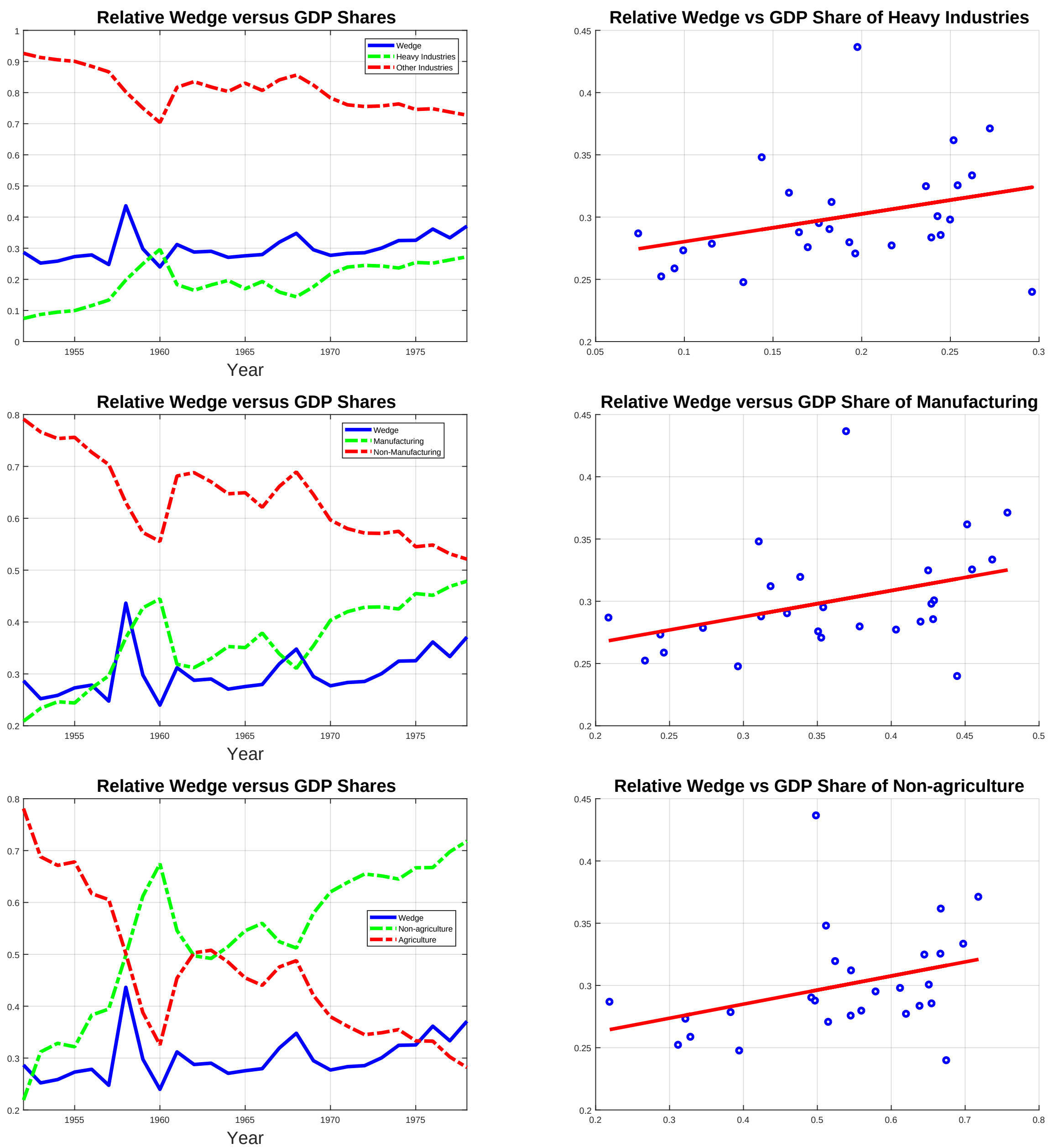


Figure 2: Relative Wedges versus GDP Shares of Capital-Intensive Industries

Figure 2 presents the pattern of the relative wedge and how it is correlated with the GDP share of the capital-intensive sector. First, the left panels show that the relative wedge has an increasing trend over time and booms during the GLF. Second, the bottom three rows document a positive correlation between the relative wedge and the GDP share of the capital-intensive sector defined in the three different ways.[17] Figure 3 documents that aggregate TFP growth is negatively correlated with the relative sectoral wedge and especially during the GLF, meaning the catch-up industrial policy leads to resource misallocation.[18] Similarly, the growth rate of GDP per capita is negatively correlated with the relative sectoral wedge and more so during the GLF, implying that the catch-up industrial policy slows down economic growth by distorting resource allocation.[19] These empirical evidence suggests that a surge in the catch-up industrial policy can lead to a spike (plummet) in the capital-intensive sector (the other sector) and a decline in GDP growth due to severe resource misallocation.

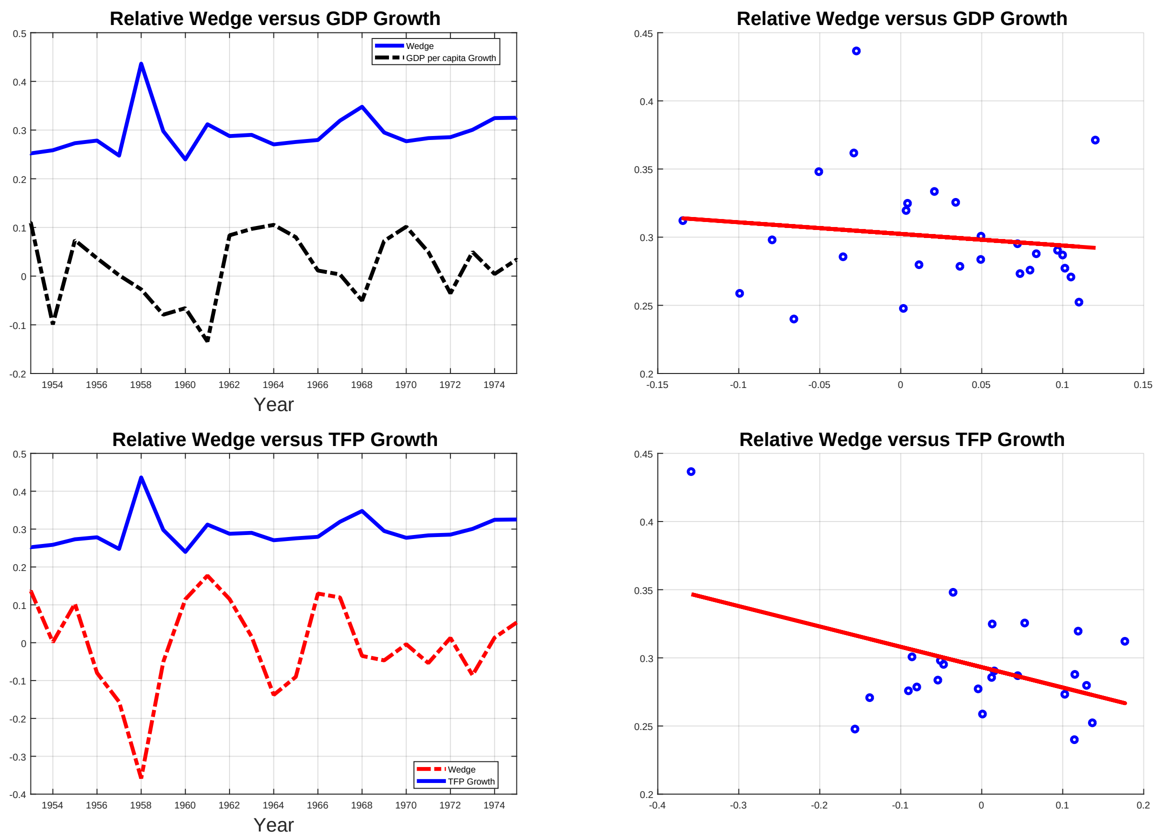


Figure 3: Relative Wedge versus TFP and GDP Growth

Next, we develop a two-sector neoclassical growth model with sectoral wedges to investigate the macroeconomic implications of the catch-up industrial policy. We show that our theoretical results are broadly consistent with the facts we document in this section.

[17]The $R$-squared of the right three panels are 0.11, 0.15, and 0.13, respectively. The coefficient of correlation between the relative wedges and GDP shraes of heavy industries, manufacturing industries, and non-agricultural industries are 0.43, 0.5, and 0.46, respectively.

[18]The $R$-squared of the right panel is 0.2. The coefficient of correlation between the relative wedge and the growth rate of GDP is $-0.45$.

[19]The $R$-squared of the right panel is 0.02. The coefficient of correlation between the relative wedge and the growth rate of GDP is $-0.14$.

# 4 Model

In this section, we firstly present our baseline model: a simple two-sector neoclassical growth model with a benevolent government (politician). We solve the competitive equilibrium of the baseline model. The steady state of the competitive equilibrium of the baseline economy is assumed to be a developed country. Then, we make an additional assumption that the government (politician) who has catch-up aspirations. We consider such an economy as the Chinese economy between 1952 and 1978, where the Chinese government adopt a distortionary industrial policy to promote the output of the target sector. The steady-state output of the target sector of the developed country is what Chinese government wants to catch up with. The optimal industrial policy is derived by solving a Ramsey allocation problem of the government. Theoretical results are derived by comparing the two economies. We show that although China may catch up with the developed country in terms of the output of the target sector by adopting the catch-up industrial policy, aggregate output and capital stock as well as the social welfare of China are lower than those of the developed country. When the degree of catch-up aspirations is high enough, even the output of the target sector is lower than that of the developed country: China can fail to catch up with the developed country in terms of the output of the target sector.

## 4.1 The Baseline Model

Time is continuous and the horizon is infinite. Time index $t$ is omitted whenever this causes no confusion. In the model economy, there is a representative household whose preference is assumed to be of the constant-relative-risk-aversion (CRRA) form. Specifically, the utility function takes the following form:

$$\int_0^\infty u(c(t))e^{-\rho t}dt, \tag{1}$$

where $c(t)$ is the consumption of the representative household at time $t$ and

$$u(c(t)) = \frac{c(t)^{1-\theta}}{1-\theta} \tag{2}$$

is the utility function of the representative household at time $t$. $\rho$ is the time discounting rate and $0 \leq \theta < 1$ is the coefficient of relative risk aversion.[20]

The household is endowed with one unit of labor and supplies it at wage rate $w$ inelastically at each time point. At time 0, the capital stock that the household owns is assumed to be $k_0$. The household rents the capital to firms at rate $r$. For simplicity, the depreciation rate of capital is set to be 0. We assume that all firms are owned by the representative household. However, since the production technologies of all firms are assumed to be constant-return-to-scale, the profits are zero

[20] The assumption $\theta < 1$ ensures that the government's utility function would be reasonable as we will discuss below.

in equilibrium. Hence, the budget constraint for the representative household is:

$$\dot{k} = w + rk - c, \tag{3}$$

where $k$ is the total capital stock that the household owns. It requires the household's expenditure on consumption and investment to be equal to the income at each time point. The representative household chooses consumption and capital to maximize the lifetime utility (1) subject to the budget constraint (3).

There are two sectors (representative firms) that produce two intermediate goods competitively via two Cobb-Douglas production technologies, respectively:

$$y_i = A_i k_i^{\alpha_i} l_i^{1-\alpha_i}, \tag{4}$$

where $i \in \{1, 2\}$ denotes sector $i$. $k_i$ and $l_i$ are capital and labor used in sector $i$. Therefore, $l_i$ is also the employment share in sector $i$. $A_i$ is the sector-level productivity parameter for sector $i$. Without loss of generality, we assume that there is no productivity growth for both sectors, namely $A_i$ is a constant over time. To distinguish the two sectors, we assume sector 2 is more capital-intensive than sector 1, that is $\alpha_1 < \alpha_2$. Output of the two sectors can only be used as intermediate inputs in the production of the unique final good.

Denote $p_i$ as the price of the intermediate good $i$. The representative firm in sector $i$ chooses $k_i$ and $l_i$ to maximize the profit at each time point:

$$p_i y_i - r k_i - w l_i. \tag{5}$$

The final good is produced competitively by combining the two intermediates $y_1$ and $y_2$ through another Cobb-Douglas production:

$$y = y_1^{\gamma} y_2^{1-\gamma}. \tag{6}$$

The final good is the numeraire. The representative firm in the final good sector choose $y_1$ and $y_2$ to maximize the profit at each time point:

$$y - p_1 y_1 - p_2 y_2. \tag{7}$$

Finally, we assume that all markets are competitive and there is a benevolent government (politician) in the baseline model. In the next subsection, we characterize the competitive equilibrium of the baseline economy.

## 4.2 Competitive Equilibrium in the Baseline Economy

In this subsection, we define and solve for the competitive equilibrium of the baseline model. The steady-state of the competitive equilibrium is then considered as the developed country that China is willing to catch up with.

The competitive equilibrium of the baseline economy is defined as follows.

**Definition 1.** Given the initial capital stock $k_0$ and the unit labor endowment at each time point, the competitive equilibrium is a combination of a feasible allocation $k_i, l_i, y_i, c, k, y$ and a price system $(p_i, r_i, w_i)$, $i = 1, 2$, for $t \in [0, \infty)$ such that: 1) given the price system, the allocation solves both the utility maximization problem of the representative household and the profit maximization problems of all firms; 2) all markets clear.

The utility maximization problem of the representative household requires the following Euler equation hold:

$$\frac{\dot{c}}{c} = \frac{r - \rho}{\theta}. \tag{8}$$

The profit maximization of sector $i$ implies:

$$r = \frac{\alpha_1 p_1 y_1}{k_1} = \frac{\alpha_2 p_2 y_2}{k_2}, \tag{9}$$

and

$$w = \frac{(1 - \alpha_1) p_1 y_1}{l_1} = \frac{(1 - \alpha_2) p_2 y_2}{l_2}. \tag{10}$$

And the following two equations are necessary for the profit maximization of the final good sector:

$$p_1 = \frac{\gamma y}{y_1}, \tag{11}$$

and

$$p_2 = \frac{(1 - \gamma) y}{y_2}. \tag{12}$$

To simplify the notation, let $\beta := \alpha_1 \gamma + \alpha_2 (1 - \gamma)$ and $0 < \beta < 1$. Notice that $k_1 + k_2 = k$. Combining (4), (9), (11) and (12), we obtain the capital allocation across the two sectors:

$$k_1 = \frac{\alpha_1 \gamma}{\beta} k, \tag{13}$$

and

$$k_2 = \frac{\alpha_2 (1 - \gamma)}{\beta} k. \tag{14}$$

Similarly, notice that $l_1 + l_2 = 1$. Combining (4), (10), (11) and (12), we obtain the labor allocation across the two sectors:

$$l_1 = \frac{(1 - \alpha_1) \gamma}{1 - \beta}, \tag{15}$$

and

$$l_2 = \frac{(1-\alpha_2)(1-\gamma)}{1-\beta}. \tag{16}$$

Substituting equations (13), (14), (15) and (16) into the production technology (4), we have the output of the two sectors, respectively:

$$y_1 = A_1\gamma\left(\frac{\alpha_1}{\beta}\right)^{\alpha_1}\left(\frac{1-\alpha_1}{1-\beta}\right)^{1-\alpha_1} k^{\alpha_1}, \tag{17}$$

and

$$y_2 = A_2(1-\gamma)\left(\frac{\alpha_2}{\beta}\right)^{\alpha_2}\left(\frac{1-\alpha_2}{1-\beta}\right)^{1-\alpha_2} k^{\alpha_2}. \tag{18}$$

And then substituting (17) and (18) into the final good production function (6), it is straightforward to derive:

$$y = Ak^{\beta}, \tag{19}$$

where

$$A = \frac{\gamma^{\gamma}(1-\gamma)^{1-\gamma}A_1^{\gamma}A_2^{1-\gamma}[\alpha_1^{\alpha_1}(1-\alpha_1)^{1-\alpha_1}]^{\gamma}[\alpha_2^{\alpha_2}(1-\alpha_2)^{1-\alpha_2}]^{1-\gamma}}{[\alpha_1\gamma+\alpha_2(1-\gamma)]^{\alpha_1\gamma+\alpha_2(1-\gamma)}[(1-\alpha_1)\gamma+((1-\alpha_2)(1-\gamma))]^{(1-\alpha_1)\gamma+(1-\alpha_2)(1-\gamma)}}. \tag{20}$$

It is straightforward to show that the capital rental rate is equal to the marginal productivity of capital and the wage rate is equivalent to the marginal productivity of labor in the competitive equilibrium:

$$r = \frac{\beta y}{k} = \beta A k^{\beta-1}, \tag{21}$$

and

$$w = (1-\beta)y = (1-\beta)Ak^{\beta}. \tag{22}$$

Our two-layer Cobb-Douglas production technology allows us to transform the two-sector model into a standard one-sector neoclassical growth model with a Cobb-Douglas aggregate product function. Thus, the consumption growth rate of the representative household becomes:

$$\frac{\dot{c}}{c} = \frac{\beta A k^{\beta-1} - \rho}{\theta}, \tag{23}$$

according to the Euler equation (8). Combining the budget constraint of the household (3), the rental rate (21) and the wage rate (22), we derive the law of motion of capital:

$$\dot{k} = y - c. \tag{24}$$

The competitive equilibrium is characterized by equations (11)-(24).[21]

Since there is no exogenous productivity growth, the model has a steady state where all variables

[21] The complete characterization should include the transversality condition.

are constants. Denote the steady-state value of $x$ by $x^*$. To derive the steady state, let $\dot{c} = \dot{k} = 0$ and we have the steady-state capital and consumption as follows:

$$k^* = \left(\frac{\beta A}{\rho}\right)^{1/(1-\beta)}, \tag{25}$$

and

$$c^* = y^* = A(k^*)^{\beta}. \tag{26}$$

The value of other allocations and prices in the steady state can be derived by substituting the steady-state value of capital into equations (11)-(22). As we argue at the beginning, the steady state output of the target sector in the competitive equilibrium of the baseline model serves as the benchmark that China is willing to catch up with. It is natural to assume any developed countries has attained its steady state.

### 4.3 The Chinese Economy

In this subsection, we describe how the China is different from the baseline economy (the developed country). Then, we formalize the catch-up aspirations by specifying the preference of the government of China. Finally, we introduce the catch-up industrial policy.

As we argue in Section 1 and 2, political leaders in China have catch-up aspirations. The baseline economy has a benevolent government who maximize the social welfare. However, China differs from the developed economy because the politician is not purely benevolent in a way that the government gains utility from the achievement of his/her own aspirations, in addition to the social welfare (utility of the representative household). Specifically, the politician aspires to boost the output of the capital-intensive sector with the intention of catching up with the developed country as soon as possible, because in his/her opinion producing as much output of the capital-intensive good as the developed country is the sign of a modernized, industrialized, developed and politically powerful country and thus the international prestige and status will be enhanced.

This difference between the two countries could be ascribed to their political institutions. That is, the developed country might have effective democracy through which citizens could force the government to act benevolently.[22] But in China, as well as in many developing countries, the political institution gives a much larger discretionary powers to the government so that the politician is able to implement policies that is designed to fulfill his/her own aspirations.[23]

[22] In a political agency model, Acemoglu et al. (2008a) demonstrate that citizens could imperfectly control a self-interested and commitment-lacking politician by using elections and then induce the government to take the same capital-income taxation structure as that predicted by the Chamley (1986) and Judd (1985) in which the government is benevolent and able to commit to policies.

[23] The non-benevolent government assumption is common in many political agency models (Barro, 1973; Ferejohn, 1986; Acemoglu et al., 2008a,b; Besley and Smart, 2007; Persson and Tabellini, 2004). Although politicians could choose policies they prefer in these models, they can be voted out of office if their choice is not in line with the electorate's expectations. Unfortunately, this mechanism doesn't work well or does not even exist in China. And thus

Formally, we assume the government gains utility from a combination of consumption of the household and the output of the target sector relative to that of the developed economy in the following form:

$$c(t)^{1-\omega}\left(\frac{y_2(t)}{y_{2,B}^*}\right)^{\frac{\omega}{1-\theta}}. \tag{27}$$

And thus the period utility function of the government is:

$$u(c(t)^{1-\omega}\left(\frac{y_2(t)}{y_{2,B}^*}\right)^{\frac{\omega}{1-\theta}}. \tag{28}$$

Therefore, the preference of the government is as follows:

$$\int_0^\infty \frac{c(t)^{(1-\theta)(1-\omega)}}{1-\theta}\left(\frac{y_2(t)}{y_{2,B}^*}\right)^{\omega} e^{-\rho t}dt, \tag{29}$$

where $\omega \in [0,1]$ denotes the politician's subjective weight of his own catch-up aspirations against the social welfare.[24] When comparing China to the baseline economy, we use subscript $B$ to denote the variables of the baseline economy. Under this preference, the politician still cares about the social welfare. But he/she also feel better from the achievement of his catch-up aspirations if $0 \leq \theta < 1$.

To fulfill his/her catch-up aspirations, the politician naturally has incentive to increase the output of sector 2 by introducing the catch-up industrial policy. It is well-documented that the agricultural sector is implicitly taxed to fund the investment of heavy industry (Sheng, 1993; Knight, 1995; Imai, 2000; Naughton, 2007; Zhu, 2012). Figure 1 shows that the investment share of the capital-intensive sector surges before 1960 and remains large afterwards, suggesting that heavy industry received positive subsidies. Specifically, the policy consists of taxing the labor-intensive sector while subsidizing the capital-intensive sector. Resources thus will be reallocated to the capital-intensive sector from the labor-intensive sector.

Formally, we assume that the government levies a marginal tax on capital return in sector 1 while subsidizes the capital return marginally in sector 2. Let the marginal tax rate and the marginal subsidy rate be $0 \leq \epsilon_0$ and $0 \leq \tau_0 \leq 1$, respectively. Since the optimal dynamic tax over time is not our focus, we further assume that the government's budget is balanced at any time point:

$$\epsilon_0 r k_1 = \tau_0 r k_2. \tag{30}$$

This equation equates the subsidy given to sector 2 to the tax levied from sector 1. This specificaiton of the industrial policy in China is jsut for simplicity. In Appendix C, we show that all the results

it is reasonable not to introduce this political mechanism into our model because we mainly focus on economic growth and development of China.

24 Here we assume the government has the same rate of time preferences as the representative citizen. Different time preferences rate could be dealt with, but it will complicate our model substantially while providing us with very limited insight.

in Section 4 and 5 are essentially the same if the industrial policy is such that 1) the government does not subsidize the capital-intensive sector; and 2) both the capital and labor return are taxed (subsidized).

To summarize, the differences between China and the developed economy are twofold. Firstly, the preference of the government in China has a part that captures catch-up aspirations while the government of the developed country is benevolent. Secondly, there is a catch-up industrial policy that is aimed to fulfill the catch-up aspirations. In the next subsection, we characterize the competitive equilibrium of the Chinese economy, taking the industrial policy as given. In subsection 4.5, we will derive the optimal policy by solving the Ramsey allocation problem.

### 4.4 Competitive Equilibrium of the Chinese Economy

Notice that the preference of the government does not affect the competitive equilibrium. Although the introduction of the catch-up industrial policy will change the behavior of the firms, it is irrelevant for the representative household. Hence, the Euler equation of the household in the baseline economy, (8), still holds in China.

Taking the policy ($\epsilon_0$ and $\tau_0$) as given, the representative firm in sector 1 and 2 maximize the profit at each time point:

$$p_1 y_1 - (1+\epsilon_0) r k_1 - w l_1, \tag{31}$$

and

$$p_2 y_2 - (1-\tau_0) r k_2 - w l_2. \tag{32}$$

To simplify the notation, let $\epsilon = \epsilon_0/(1+\epsilon_0) \in [0,1)$ and $\tau = \tau_0/(1-\tau_0) \in [0,\infty)$. Notice that $\epsilon$ and $\tau$ are monotonically increasing in $\epsilon_0$ and $\tau_0$, respectively. The budget constraint of the government at each time point becomes:

$$\epsilon \alpha_1 p_1 y_1 = \tau \alpha_2 p_2 y_2. \tag{33}$$

Substituting conditions (11) and (12) into the above equation derives the relationship between the two rates:

$$\epsilon = \frac{\alpha_2(1-\gamma)}{\alpha_1 \gamma} \tau. \tag{34}$$

Hence, we consider $\tau$ as the catch-up industrial policy that the government adopts in the rest of the paper. That is, the government chooses $\epsilon$ and $\tau$ to maximize his/her utility. Before jumping to the optimal policy problem, we need to derive the competitive equilibrium of China, which is defined as below.

**Definition 2.** Given the catch-up industrial policy ($\epsilon$ and $\tau$) and the initial capital stock $k_0$, the competitive equilibrium is a combination of a feasible allocation $k_i, l_i, y_i, c, k, y$ and a price system $(p_i, r_i, w_i)$, $i = 1, 2$, for $t \in [0, \infty)$ such that: 1) given the price system, the allocation solves both the utility maximization problem of the representative household and the profit maximization problems of all firms; 2) all markets clear; 3) the government's budget constraint (33) is balanced at any time point.

Most of the necessary conditions that characterizes the competitive equilibrium in the baseline model still hold except the first-order conditions with respect to capital in the profit maximization of firms in the two intermediate sectors. These equations becomes:

$$r = \frac{(1+\epsilon_0)\alpha_1 p_1 y_1}{k_1} = \frac{(1-\tau_0)\alpha_2 p_2 y_2}{k_2}. \tag{35}$$

Combining (4), (11), (12) and (35), we derive the capital allocation across the two sectors as follows:

$$k_1 = \frac{\beta - \alpha_2(1-\gamma)(1+\tau)}{\beta} k, \tag{36}$$

and

$$k_2 = \frac{\alpha_2(1-\gamma)(1+\tau)}{\beta} k. \tag{37}$$

Substituting equations (15), (16), (36) and (37), into the production technology (4), we obtain the output of the two sectors, respectively:

$$y_1 = A_1\gamma \left(\frac{\alpha_1}{\beta}\right)^{\alpha_1} \left(\frac{1-\alpha_1}{1-\beta}\right)^{1-\alpha_1} \left(1 - \frac{\alpha_2(1-\gamma)\tau}{\alpha_1\gamma}\right)^{\alpha_1} k^{\alpha_1}, \tag{38}$$

and

$$y_2 = A_2(1-\gamma) \left(\frac{\alpha_2}{\beta}\right)^{\alpha 2_1} \left(\frac{1-\alpha_2}{1-\beta}\right)^{1-\alpha_2} (1+\tau)^{\alpha_2} k^{\alpha_2}. \tag{39}$$

And then substituting (17) and (18) into the final good production function (6), it is straightforward to derive:

$$y = Af(\tau)k^{\beta}, \tag{40}$$

where $f(\tau)$ is the endogenous TFP and is defined as follows:

$$f(\tau) = (1+\tau)^{\alpha_2(1-\gamma)} \left(1 - \frac{\alpha_2(1-\gamma)\tau}{\alpha_1\gamma}\right)^{\alpha_1\gamma}. \tag{41}$$

To have positive capital input in sector 1, the subsidy/tax rate can not be too large. specifically, we assume that the subsidy rate is bounded above as follows:

$$\tau < \frac{\alpha_1\gamma}{\alpha_2(1-\gamma)}. \tag{42}$$

Notice that $\tau$ could be larger than 1 when $\alpha_1\gamma$ is larger than $\alpha_2(1-\gamma)$. The following lemma summarizes how the subsidy rate affect the production in the two sectors and the final good production.

**Proposition 1.** *At any time point, the immediate (static) effects of an increase of the subsidy rate $\tau$ are 1) a smaller final output; 2) a larger output and capital input in sector 2; 3) a smaller output* *and capital input in sector 1; 4) a larger reallocation of capital between the two sectors.*

*Proof.* It is easy to show that $f(0) = 1$ and $f(\tau)$ is a decreasing function of the subsidy rate $\tau$. Therefore, the final output is maximized when there is no subsidy and tax. This case coincides with the developed country. According to equations (36) to (40), it is straightforward to show the following comparative statics for any time point:

$$\frac{\partial y}{\partial \tau} < 0; \frac{\partial y_1}{\partial \tau} < 0; \frac{\partial y_2}{\partial \tau} > 0; \frac{\partial k_1}{\partial \tau} < 0; \frac{\partial k_2}{\partial \tau} > 0. \tag{43}$$

This completes the proof. □

When there is no subsidy, the economy coincides with the baseline model. When the subsidy rate departs from zero and becomes larger, the TFP is lower and so is the final output. This reflects the misallocation effect of the industrial policy. Due to this policy, the capital allocation is distorted in a way that resources are reallocated to the capital-intensive sector from the labor-intensive sector. The reallocation of capital between the two sectors helps increase the output of the target sector. This result is what the government is happy to have. However, the increase of the capital-intensive sector is at the expense of the output of the labor-intensive sector.

Proposition 1 is consistent with the empirical facts on sectoral GDP shares and GDP growth depicted in Figure 1-3. The Chinese government initiates the catch-up industrial policy and invests heavily in the capital-intensive sector since 1953. As a result, the GDP share of capital-intensive sector booms immediately. However, both TFP and GDP growth decline.

Notice that the final output and the output of both sectors are increasing in the aggregate capital stock. A lower final output today leads to less investment and hence the capital accumulation will be lower. Eventually, the capital stock might be low enough so that the final output and even the output of the capital-intensive sector will be lower than those of the developed country. We will discuss more about the static and dynamic effects of the industrial policy in Section 4.5 and 5.

It is straightforward to show that, in the competitive equilibrium, the capital rental rate is equal to the marginal productivity of capital and the wage rate is equivalent to the marginal productivity of labor of the final good production function:

$$r = \frac{\beta y}{k} = \beta A f(\tau) k^{\beta - 1}. \tag{44}$$

and

$$w = (1-\beta) y = (1-\beta) A f(\tau) k^{\beta}. \tag{45}$$

Therefore, the consumption growth rate of the representative household becomes:

$$\frac{\dot{c}}{c} = \frac{\beta A f(\tau) k_f^{\beta - 1} - \rho}{\theta}. \tag{46}$$

Combining the budget constraint of the household (3), the rental rate (44) and the wage rate (45) yields the law of motion of capital:

$$\dot{k} = y - c. \tag{47}$$

The competitive equilibrium is characterized by equations (11), (12), (15), (16), (36)-(40), (44)-(47).[25]

The competitive equilibrium takes the catch-up industrial policy as given. However, different policies lead to different allocations and prices. In the next subsection, we introduce and solve the Ramsey allocation problem of the government to derive the optimal sector-oriented industrial policy.

### 4.5 The Ramsey Problem and the Optimal Policy

In this subsection, we firstly define and solve the Ramsey allocation problem. Then, we characterize the effect of the degree of catch-up aspirations on the optimal policy and equilibrium allocation at the steady state.

**Definition 3.** The Ramsey allocation problem for the government is to select a competitive equilibrium allocation $k_i, l_i, y_i, c, k, y$, $i = 1, 2$, of the China by choosing a policy $\tau$ to maximize his/her utility (29). The solution for this problem is called the Ramsey allocation and the optimal policy. The corresponding competitive equilibrium is called the Ramsey equilibrium.

It should be noticed that the above Ramsey problem is quite different from the standard Ramsey problem in the literatures.[26]. The main difference is that the government in our problem has a preference that is a weighted average of both the social welfare and his/her own target while the government is benevolent in the standard Ramsey problem. We believe that our assumption is much closer to the reality of China, since individuals are not able to tie the hands of the government of China.

Substituting (39) into the preference of the government yields

$$\max_{\tau} \int_0^{\infty} \Phi c^{(1-\theta)(1-\omega)} (1+\tau)^{\alpha_2 \omega} k^{\alpha_2 \omega} e^{-\rho t} dt, \tag{48}$$

where $\Phi$ is a constant:

$$\Phi = \frac{A_2^{\omega} [\alpha_2 (1-\gamma)]^{\alpha_2 \omega} l_2^{(1-\alpha_2)\omega}}{(1-\theta)^{1+(1-\theta)(1-\omega)} \beta^{\alpha_2 \omega} \left( y_{2,B}^{*} \right)^{\omega}}. \tag{49}$$

$y_{2,B}^{*}$ is given by equation (18) and (25), and $l_2$ is a constant given by equation (16).

Notice that, given the policy $\tau$, the competitive equilibrium allocation of the Chinese economy is dictated by two differential equations (46) and (47). These two equations serve as the implementability

[25] Again, the complete characterization should include the transversality condition.

[26] For the Ramsey taxation literature, see (Chamley, 1986; Judd, 1985; Benhabib and Rustichini, 1997) and for the dynamic Mirrlees taxation, see (Golosov et al., 2003; Kocherlakota, 2005; Albanesi and Sleet, 2006)

constraints of the Ramsey allocation problem.[27] Therefore, the Ramsey problem reduce to choosing a subsidy rate $\tau$ to maximize the utility of the government in (48) subject to equations (46) and (47), in addition to the inequality (42). The Ramsey problem is thus simplified to be a standard optimal control problem.

The Hamiltonian of the Ramsey allocation problem is

$$H = \Phi c^{(1-\theta)(1-\omega)}(1+\tau)^{\alpha_2\omega}k^{\alpha_2\omega} + \frac{\lambda c}{\theta}\left(\beta A f(\tau)k^{\beta-1} - \rho\right) + \eta\left(Af(\tau)k^{\beta} - c\right) + \phi\left(\frac{\alpha_1\gamma}{\alpha_2(1-\gamma)} - \tau\right), \tag{50}$$

where $\lambda$ and $\eta$ are Hamiltonian multipliers corresponding to equations (46) and (47), respectively, and $\phi$ is the Lagrangian multiplier associated with constraint (42). The necessary conditions are as follows:

$$\frac{\partial H}{\partial \tau} = \alpha_2\omega\Phi c^{(1-\theta)(1-\omega)}(1+\tau)^{\alpha_2\omega-1}k^{\alpha_2\omega} + \left(\frac{\lambda\beta c}{\theta} + \eta k\right)Af'(\tau)k^{\beta-1} - \phi = 0, \tag{51}$$

$$\dot{\lambda} = \lambda\rho + \frac{(1-\theta)(1-\omega)(1+\tau)}{\alpha_2\omega c}\left(\frac{\lambda\beta c}{\theta} + \eta k\right)Af'(\tau)k^{\beta-1} - \lambda\frac{\dot{c}}{c} + \eta, \tag{52}$$

$$\dot{\eta} = \eta\rho + Ak^{\beta-2}\left[\left(\frac{\lambda\beta c}{\theta} + \eta k\right)\left((1+\tau)f'(\tau) - \beta f(\tau)\right) + \frac{\lambda\beta c}{\theta}f(\tau)\right], \tag{53}$$

and $\tau \leq \frac{\alpha_1\gamma}{\alpha_2(1-\gamma)}$, $\phi \geq 0$ and $\phi\left(\frac{\alpha_1\gamma}{\alpha_2(1-\gamma)} - \tau\right) = 0$.

We first show that the subsidy rate never touches the upper bound.

**Lemma 1.** *The inequality (42) never binds for any $\omega > 0$.*

*Proof.* It is sufficient to prove that $\phi = 0$. Suppose $\phi > 0$. Differentiating $f(\tau)$ yields

$$\frac{(1+\tau)f'(\tau)}{f(\tau)} = -\frac{\alpha_2(1-\gamma)\beta\tau}{\alpha_1\gamma - \alpha_2(1-\gamma)\tau}. \tag{54}$$

If $\phi > 0$, we have $\tau = \frac{\alpha_1\gamma}{\alpha_2(1-\gamma)}$. But then, the above equation implies $f'(\tau) = -\infty$, contradicting to the first-order condition (51). Hence, we conclude that $\phi = 0$ and the constraint never binds. This completes the proof. □

The Ramsey equilibrium is fully dictated by equations (46), (47), (51), (52), (53). The long-run equilibrium of the economy is characterized by the steady state. The following proposition shows that the Ramsey equilibrium has a unique steady state.

[27]Technically, the transversality condition is also necessary. However, it is a boundary condition that is always satisfied in our model. This condition is omitted in the rest of this paper.

**Proposition 2.** *There is a unique steady state for the Ramsey equilibrium. In particular, we have*

$$k^* = \left(\frac{\beta A f(\tau^*)}{\rho}\right)^{1/(1-\beta)}, \tag{55}$$

$$c^* = \left(\frac{\beta}{\rho}\right)^{\beta/(1-\beta)} (A f(\tau^*))^{1/(1-\beta)}, \tag{56}$$

*and*

$$\tau^* = \frac{\alpha_1 \gamma \omega (1-\beta)}{(1-\gamma)[\alpha_2 \omega (1-\beta\theta) + \beta(1-\beta)(1-\theta)(1-\omega)]}. \tag{57}$$

*Proof.* Because there is no productivity growth in our model, $k$, $c$, $\lambda$ and $\eta$ are constants in the steady state. Let $\dot{k} = \dot{c} = 0$. We have

$$A f(\tau) k^{\beta-1} = \frac{c}{k} = \frac{\rho}{\beta}. \tag{58}$$

Substituting the above equation into (52) and (53) and rearranging the two equations, we obtain

$$\dot{\lambda} = \frac{\lambda\rho}{\theta}\left[\theta + \frac{(1-\theta)(1-\omega)(1+\tau)f'(\tau)}{\alpha_2 \omega f(\tau)}\right] + \eta\left[1 + \frac{(1-\theta)(1-\omega)(1+\tau)f'(\tau)}{\alpha_2 \omega f(\tau)}\right] - \lambda\frac{\dot{c}}{c}, \tag{59}$$

and

$$\dot{\eta} = \left[\frac{\lambda\rho}{\theta}\left(\frac{(1+\tau)f'(\tau)}{f(\tau)} + 1 - \beta\right) + \eta\frac{(1+\tau)f'(\tau)}{f(\tau)}\right]\frac{\rho}{\beta}. \tag{60}$$

Let $\dot{\lambda} = \dot{\eta} = 0$. We have

$$\frac{(1+\tau)f'(\tau)}{f(\tau)} = -\frac{\alpha_2 \omega (1-\beta)}{(1-\theta)[\alpha_2 \omega + (1-\beta)(1-\omega)]}. \tag{61}$$

Combining together equation (54) and (61) immediately leads to the steady-state subsidy rate $\tau^*$. Finally, $k^*$ and $c^*$ are derived from equation (58). □

The parameter that captures the degree of catch-up aspirations of the government is $\omega$. The following two propositions study how the willingness to catch up affects the steady state. The two propositions are immediate implications of Proposition 2 and we state them without proof.

**Proposition 3.** *The steady-state subsidy rate $\tau^*$ is an increasing function of $\omega$ and satisfies the following properties:*

$$\lim_{\omega \to 0} \tau(\omega) = 0 \tag{62}$$

*and*

$$\lim_{\omega \to 1} \tau(\omega) = \frac{\alpha_1 \gamma (1-\beta)}{\alpha_2 (1-\gamma)(1-\beta\theta)}. \tag{63}$$

**Proposition 4.** *In the steady state, the capital $k^*$, consumption $c^*$, the final output $y^*$, the capital input of sector $i = \{1, 2\}$, $k_i^*$ and the output of sector $i = \{1, 2\}$, $y_i^*$ are decreasing functions of $\omega$.*

*In addition, we have*

$$\lim_{\omega\to 0} k^* = k^*_B,\ \lim_{\omega\to 0} c^* = c^*_B,\ \lim_{\omega\to 0} y^* = y^*_B,\ \lim_{\omega\to 0} k^*_i = k^*_{i,B},\ \textit{and}\ \lim_{\omega\to 0} y^*_i = y^*_{i,B}. \tag{64}$$

Propositions 2 to 4 show that a higher degree of catching up (i.e. a larger $\omega$) requires a larger steady-state subsidy rate $\tau^*$ and all aggregate variables as well as variables in sector 1 are lower in the steady state. As we described in section 4.3, $\omega$ denotes the weight the government gives to catch-up aspirations. The higher the weight is, the higher priority the government would give to the development of target sector and, therefore, the more heavily distorted industrial policy the government would introduce. As a result, a higher $\omega$ leads to a higher steady-state subsidy rate $\tau^*$. However, the aggregate economic performance is very bad as demonstrated in Proposition 3 and 4.

Notice that the catch-up aspiration $\omega$ is believed much stronger in the GLF than the First Five-Year Plan period. Proposition 3 implies that the catch-up industrial policy is stronger as well. This is consistent with the empirical evidence in Figure 2 and 3 where our measure of the catch-up industrial policy is much larger during the GLF than in the First Five-Year Plan period.

Results in Proposition 2 to 4 are in line with the idea of conditional convergence. Proposition 2 implies that two countries where the degree of catch-up aspirations of their governments are different will not converge to the same steady state, even if everything else is the same between the two countries. China in our model could catch up with the developed country, in terms of the aggregate output per capita, in the baseline model only when the government completely abandons his/her catch-up aspirations ($\omega = 0$).

Another variable that we are interested in is the output of sector 2. Proposition 1 shows that the output of sector 2 boosts due to the sector-oriented industrial policy. Is the optimal catch-up industrial policy effective in the long run? Before answer the question, we firstly provide a lemma that characterizes how the degree of catch-up aspirations affects the output of sector 2 in the steady state.

**Lemma 2.** *The steady-state output of sector 2 $y^*_2$ satisfies the following property:*

$$\frac{\partial y^*_2}{\partial \omega} = \begin{cases} > 0 & if\ \omega < \frac{(1-\theta)(1-\beta)}{(1-\theta)(1-\beta)+\alpha_2\theta} \\ \leq 0 & if\ \omega \geq \frac{(1-\theta)(1-\beta)}{(1-\theta)(1-\beta)+\alpha_2\theta} \end{cases}, \tag{65}$$

*that is, $y^*_2$ is an increasing function of $\omega$ if $\omega$ is not large enough and a decreasing function of $\omega$ otherwise.*

*Proof.* It is straightforward to derive

$$y^*_2 = y^*_{2,B}(1+\tau^*)^{\alpha_2} f(\tau^*)^{\frac{\alpha_2}{1-\beta}}. \tag{66}$$

Differentiating the above equation with respect to $\tau^*$ yields:

$$\frac{\partial y_2^*}{\partial \tau^*} = \alpha_2 y_{2,B}^* (1+\tau^*)^{\alpha_2 - 1} f(\tau^*)^{\frac{\alpha_2}{1-\beta}} \left(1 + \frac{(1+\tau^*)f'(\tau^*)}{(1-\beta)f(\tau^*)}\right). \tag{67}$$

Substituting (61) into the above equation and evaluating at the steady state, we obtain equation (65). □

Now, we are ready to answer the question that whether the optimal policy is effective in the long run or not? The answer is that it depends on the degree of catch-up aspirations of the government. Proposition 5 summarize the results.

**Proposition 5.** *If the following inequality holds*

$$(1+\tau(1))^{1-\alpha_1\gamma} \left(1 - \frac{\alpha_2(1-\gamma)\tau(1)}{\alpha_1\gamma}\right)^{\alpha_1\gamma} < 1, \tag{68}$$

*then there exists a unique* $\omega^*$ *such that* $y_2^* > y_{2,B}^*$ *when* $\omega < \omega^*$ *and* $y_2^* \leq y_{2,B}^*$ *when* $\omega \geq \omega^*$*, where* $\omega^*$ *satisfies the following equation:*

$$(1+\tau(\omega^*))^{1-\alpha_1\gamma} \left(1 - \frac{\alpha_2(1-\gamma)\tau(1)}{\alpha_1\gamma}\right)^{\alpha_1\gamma} = 1, \tag{69}$$

*and* $\tau(\omega)$ *is the steady state of* $\tau$ *as a function of* $\omega$*. If the inequality (68) does not hold, then* $y_2^* > y_{2,B}^*$ *for any* $\omega \in (0,1]$.

*Proof.* If $\tau^* = 0$, we have $f(\tau^*) = 1$ and thus $y_2^* = y_{2,B}^*$ according to equation (66). It follows from Lemma 2 immediately that $y_2^* > y_{2,B}^*$ when $\omega < (1-\theta)(1-\beta)/[(1-\theta)(1-\beta)+\alpha_2\theta]$. Obviously, when $\omega \geq (1-\theta)(1-\beta)/[(1-\theta)(1-\beta)+\alpha_2\theta]$, it is possible to get $y_2^* < y_{2,B}^*$. $f(\tau^*)$ would be 0 if $\tau^*$ approaches to its upper bound $\alpha_1\gamma/(\alpha_2(1-\gamma))$. By continuity, $y_2^*$ would be smaller than $y_{2,B}^*$ when $\tau^*$ is close enough to its upper bound. Notice that $\tau^*$ is increasing in $\omega$. To establish Corollary 5, therefore, it is sufficient to make sure $y_2^* < y_{2,B}^*$ when the $\omega = 1$. This leads to the inequality (68). It follows that the cutoff value of $\omega$ has to satisfy equation (69). By the definition of inequality (68), when $y_2^*$ is always larger than $y_{2,B}^*$ for any $\omega$. □

Propositions 2 to 5 demonstrates how the catch-up industrial policy affect the long-run economic performance. In the long run, the output of sector 1, the final output, the aggregate consumption and the capital stock are all smaller than those in the developed country of the baseline model. Regarding the output of the target sector, the government of China could produce more capital-intensive good than the developed country by adopting the catch-up industrial policy, if the government does not put too much weight $\omega$ on his/her catch-up aspirations. If $\omega$ is too large, the industrial policy will be more distortionary and thus capital accumulation will be too small. Consequently, the long-run capital stock will be lower than that of the developed economy, which eventually leads to less capital allocation in sector 2 even though sector 2 is the target sector.

The catch-up industrial policy has two effects: a static effect and a dynamic effect. As we discuss in Section 4.2, the static effect reflects the immediate effect of the misallocation of capital between the two sectors due to the industrial policy. The misallocation of capital incurs a lower final output, which results in a lower capital accumulation and hence a slower growth rate of capital. This dynamic effect of the industrial policy eventually leads to a lower final output. To illustrate the two effects more clearly, combine equations (17) and (38), (18) and (39), and (19) and (40):

$$\frac{y_1}{y_{1,B}} = \left(1 - \frac{\alpha_2(1-\gamma)\tau}{\alpha_1\gamma}\right)^{\alpha_1} \left(\frac{k}{k_B}\right)^{\alpha_1}, \tag{70}$$

$$\frac{y_2}{y_{2,B}} = (1+\tau)^{\alpha_2} \left(\frac{k}{k_B}\right)^{\alpha_2}, \tag{71}$$

$$\frac{y}{y_B} = f(\tau) \left(\frac{k}{k_B}\right)^{\beta}. \tag{72}$$

These three equations compare the output of the two sectors and the final output of China and the developed economy at any time $t > 0$. The first part of the RHS of the three equations above is the static effect while the second part is the dynamic effect. Clearly, the first part captures the effect of capital reallocation between the two sectors. The reallocation of capital increases the output of sector 2 but depresses the output of sector 1 and hence the final output.

The second part consists of the capital stock in China relative to the developed country. It captures the dynamic effect since the capital stock reflects the accumulation of capital in the past. Obviously, less capital accumulation in China has negative effects on the final output and the output of the two sectors. Therefore, for the final output and the output of sector 1, both the static and the dynamic effects are negative, meaning the long-run effect of industrial policy on sector 1 and the aggregate economy is unambiguously negative. However, the static effect on the output of sector 2 is positive. The long-run effect of industrial policy depends on which effect dominates the other. Proposition 5 provides the condition under which dynamic effect dominates the static effect.

It is interesting to briefly discuss the condition that ensures the dynamic effect dominates the static one. A large enough $\theta$ is sufficient to make sure condition (68) hold. Intuitively, a larger $\theta$ means a smaller inter-temporal elasticity of substitution. Hence, the household is more reluctant to reduce his/her consumption when the distortionary industrial policy is introduced. Therefore, the capital accumulation is slower and the steady-state capital will be lower. When $\theta$ is large enough, the capital accumulation will be slow enough so that the steady- state capital stock will be lower that that in the baseline model.

In this section, we focus on the theoretical analysis and explore static properties so far. Transitional dynamics analysis is not analytically tractable. In the next section, we will discuss the transitional dynamics of the Chinese economy as well as the baseline model numerically.

Lemma 1 implies that we could write $\tau$ as a function: $\tau(k, c, \lambda, \eta)$. Substituting it into equations (46), (47), (52) and (53), we obtain a dynamical system of four variables $k$, $c$, $\lambda$ and $\eta$, in which $k$

and $c$ are state variables and $\lambda$ and $\eta$ are co-states. We analyze transitional dynamics in the next section.

# 5 Transitional Dynamics

In this section, we conduct theoretical as well as numerical exercises to analyze transitional dynamics of the Ramsey equilibrium. To begin with, we establish the local stability of the dynamical system of the Ramsey equilibrium and derive the dynamic property of the optimal industrial policy near the steady state. Secondly, we choose empirically plausible parameter values and solve the model numerically. Then, we derive the dynamic path and the steady state of the Ramsey equilibrium. In the last part, various robustness checks are conducted.

Through out this section, we assume $\theta = \beta$. This assumption greatly simplifies the dynamical system thus ensures the tractability of the analysis of transitional dynamics, both theoretically and numerically.[28]

## 5.1 Theoretical Results

We first show that the 4-dimensional dynamical system of the Ramsey equilibrium can be rewritten as a 3-dimensional system which is highly tractable. Then, we establish the local stability of the dynamical system of the Ramsey equilibrium. Finally, we prove that the optimal subsidy rate is non-decreasing over time near the steady state.

Firstly, we construct a 3-dimensional dynamical system from the original 4-dimensional one. Let $z = \lambda\beta c/\theta + \eta k$. Differentiating $z$ with respect to time, we obtain $\dot{z}$ as follows:

$$\dot{z} = \frac{\lambda\beta c}{\theta}\left(\frac{\dot{\lambda}}{\lambda} + \frac{\dot{c}}{c}\right) + \eta k\left(\frac{\dot{\eta}}{\eta} + \frac{\dot{k}}{k}\right). \tag{73}$$

Substituting differential equations (46), (47), (52) and (53) into (73) yields

$$\frac{\dot{z}}{z} = \rho + Af(\tau)k^{\beta-1}\left[\frac{(1-\theta)(1-\omega)+\alpha_2\omega}{\alpha_2\omega}\cdot\frac{(1+\tau)f'(\tau)}{f(\tau)} + 1 - \beta\right]. \tag{74}$$

Notice that the law of motion of $z$ only evolves $k$. This implies the original system can be transformed into a 3-dimensional one: differential equations (46), (47) and (74), and equation (51). The following proposition establishes the local stability of this dynamical system.

**Proposition 6.** *The dynamical system (46), (47) and (74) is saddle-path stable, that is in the neighborhood of $c^*$, $k^*$ and $z^*$ there is a unique stable manifold that converges to $c^*$, $k^*$ and $z^*$.*

[28] This assumption does not crucial for most of our results in this section. In Appendix D, we provide a discrete-time version of our model. We show that the dynamical system of the Ramsey equilibrium there is saddle-path stable locally without assuming $\theta = \beta$.

*Proof.* See Appendix B. □

Proposition 6 shows that when the initial values of capital, labor and the subsidy rate are not too far away from the steady state, the economy will converge to the steady state along a unique dynamic path. In particular, consumption and capital stock are increasing over time. For the entire dynamic path, the consumption-capital ratio is constant and hence they grow at the same rate for any time. These results help us characterize the dynamic path of the optimal subsidy rate around the steady state, which is summarized in the following proposition.

**Proposition 7.** *Given the initial capital stock $k_0 < k^*$, both the aggregate capital stock $k$ and the optimal subsidy rate $\tau$ increase monotonically over time and converges to their steady state $k^*$ and $\tau^*$, respectively.*

*Proof.* See Appendix B. □

Proposition 7 demonstrates that when the initial capital stock is smaller than its steady-state level, the optimal subsidy rate becomes larger and larger as time goes by. The industrial policy is relatively more distortionary in the later stage of the development. In the early stage of the development, the economy is too poor and the optimal subsidy/tax can not be large since a large subsidy means a very low social welfare. When the capital stock is large enough, a heavily distortionary industrial policy fulfills the catch-up aspirations quite well without affecting too much of the social welfare. Since the government takes into account both the output of the target sector and the social welfare, the optimal industrial policy increases over time monotonically.

Proposition 7 implies that the catch-up industrial policy becomes stronger and stronger over time for any given catch-up aspiration. This is consistent with the empirical pattern in Figure 2 and 3 where our measure of the catch-up industrial policy increases over time except the GLF when the catch-up aspiration is enormous.

### 5.2 Numerical Results

In this subsection, we solve for the Ramsey allocation equilibrium numerically for different values of $\omega$. The purpose of the numerical exercises is to show how the degree of catch-up aspirations ($\omega$) affects 1) the steady-state utility of the government; 2) the convergence speed of the capital stock; and 3) the dynamic path of the equilibrium allocations. The dynamic path of equilibrium allocation is consistent with the empirical facts documented in Section 3.

We choose empirically plausible parameter values from the literature. Notice that all parameters except $\omega$ either dictate the preference or determines technology. Firstly, $A_1$ and $A_2$ are normalized to be unity. As is standard in the literature, we set $\rho = 0.08$ for the time preference. The income

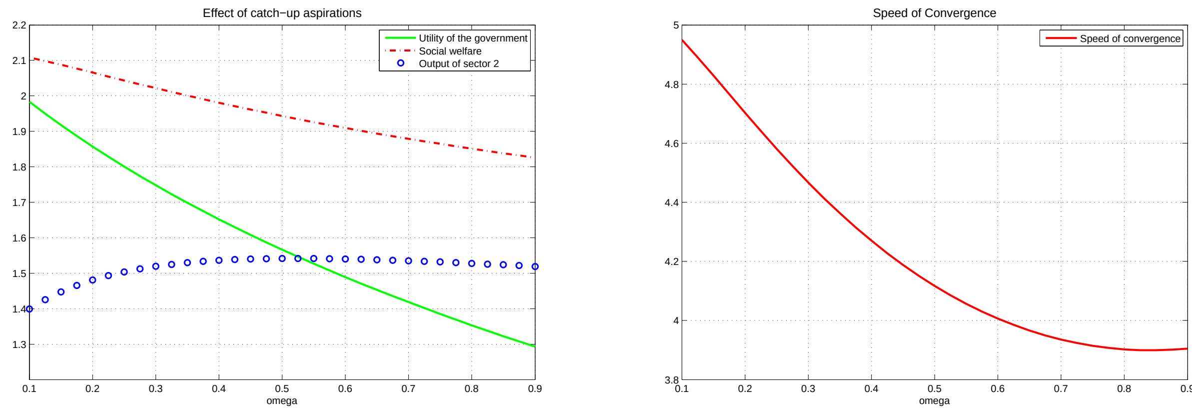


Figure 4: Steady-State Effects of $\omega$

share of capital in the two sectors $\alpha_1 = 0.35$ and $\alpha_2 = 0.65$.[29] We set the income share of sector 1, $\gamma$, to be 0.7, reflecting the fact that the bulk of most less-developed economies is labor-intensive industries. Hence, by the definition of $\beta$, we have $\beta = \theta = 0.44$. Our numerical results are very robust to our choice of parameter values.[30] In the numerical exercises, we vary the value of $\omega$ to see how the degree of catch-up aspirations affects variables that we are interested in.

Firstly, the left panel of Figure 4 shows how the degree of catch-up aspirations of the government affects the utility of the government and the social welfare in the steady state. Obviously, a higher degree of catch-up aspirations lead to a lower social welfare because of the distortionary industrial policy. Our theoretical result in Proposition 5 means the output of the capital-intensive sector increases when $\omega$ is small and increases when $\omega$ is large. Since the government gains utility from both the social welfare and the output of the target sector, the effect of catch-up aspirations on the government's utility, therefore, depends on the effect on the two components as well as the magnitude of $\omega$. When $\omega$ is small, stronger catch-up aspirations means lower social welfare but larger output of sector 2. However, since $\omega$ is small, the effect on the social welfare dominates. Hence, the utility of the government goes down. When $\omega$ becomes larger, the effect on the output of sector 2 is still dominated since the output of sector 2 does not change too much. This is exactly what happens in our numerical exercises. The result means the catch-up aspirations even hurt the government itself. This result is consistent with the empirical pattern during the first Five-Year Plan period and the GLF (1953-1960) in Figure 2 and 3 where, as the catch-up aspiration/industrial policy becomes stronger, 1) GDP growth declines; and 2) the GDP share of the capital-intensive sector increases (decreases) when the the catch-up aspiration/industrial policy is strong (weak) enough.

In Section 4, we show that economies with different degree of catch-up aspirations, $\omega$, converge

[29] Acemoglu and Guerrieri (2008) estimate that $\alpha_1 = 0.52$ and $\alpha_2 = 0.72$ in the US. Since China has less capital intensive technologies in both sectors, we choose smaller values. However, the numerical results are very robust with respect to these values.

[30] Results of sensitivity analyses are available upon request.

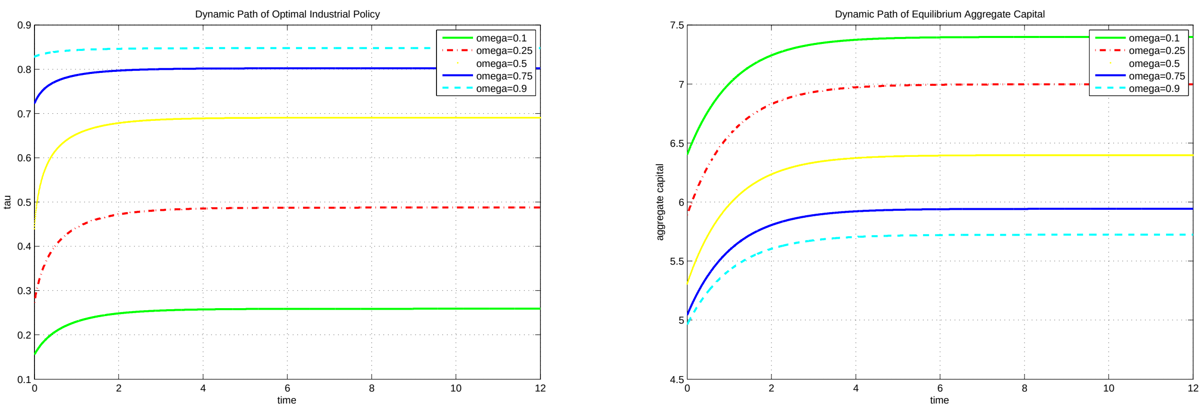


Figure 5: Dynamics of the Optimal Subsidy and the Aggregate Capital Stock

to different steady states. Now, we calculate the speed of convergence by solving for the negative eigenvalue and show that $\omega$ also affects the speed of convergence to the steady state. The right panel of Figure 4 show how the degree of catch-up aspirations affect the speed of convergence measured by the half-life for convergence. Our results imply that the economy with stronger catch-up aspirations will converge faster to the steady state. The reason is that the steady state of capital is lower when $\omega$ is greater. Hence, it is easier to reach the steady state and the speed of convergence is higher. Notice that when $\omega$ is very small the half-life for convergence is around 5 years. This is consistent with the prediction of the standard neoclassical growth model with reasonable parameter values.

Our model is not tractable enough to derive the entire dynamic path in a closed form. Next, we numerically solve for the dynamic path of the allocations of the Ramsey equilibrium.[31] Moreover, we derive the dynamic paths for different values of $\omega$ to see how the degree of catch-up aspirations affect the equilibrium dynamic path. Figure 5 shows that the aggregate capital stock and the optimal industrial policy increase over time even far away from the steady state.[32]

The upper left panel of Figure 6 shows that the aggregate output is monotone when $\omega$ is small and large. But, if $\omega$ is medium, the $y$ decreases initially and then increases over time. A small $\omega$ means the negative effect of misallocation is small while the effect of capital accumulation is large. Hence, the aggregate output goes up monotonically. But, when $\omega$ becomes larger and larger, the effect of misallocation is large enough. This effect dominates when the capital stock is small. Eventually, when the economy accumulates enough capital stock, this negative effect is dominated and the aggregate output is going up over time. When $\omega$ is very large, the optimal subsidy rate will not change too much but the capital has to accumulate and converge to the steady state. The effect of the later is dominating. Consequently, the aggregate output is monotonically increasing.

[31] We use the reverse shooting method (Judd, 1998; Miranda and Fackler, 2002). We firstly discretize the dynamical system of (46), (47) and (74) by the fourth-order Runge-Kunta method. Then we squeeze out the stable manifold from some initial values close enough to the steady state by the standard IPV method.

[32] Since we show that $c(t)/k(t) = \rho\beta$ globally, the dynamic path of the consumption is exactly the same as that of the capital stock.

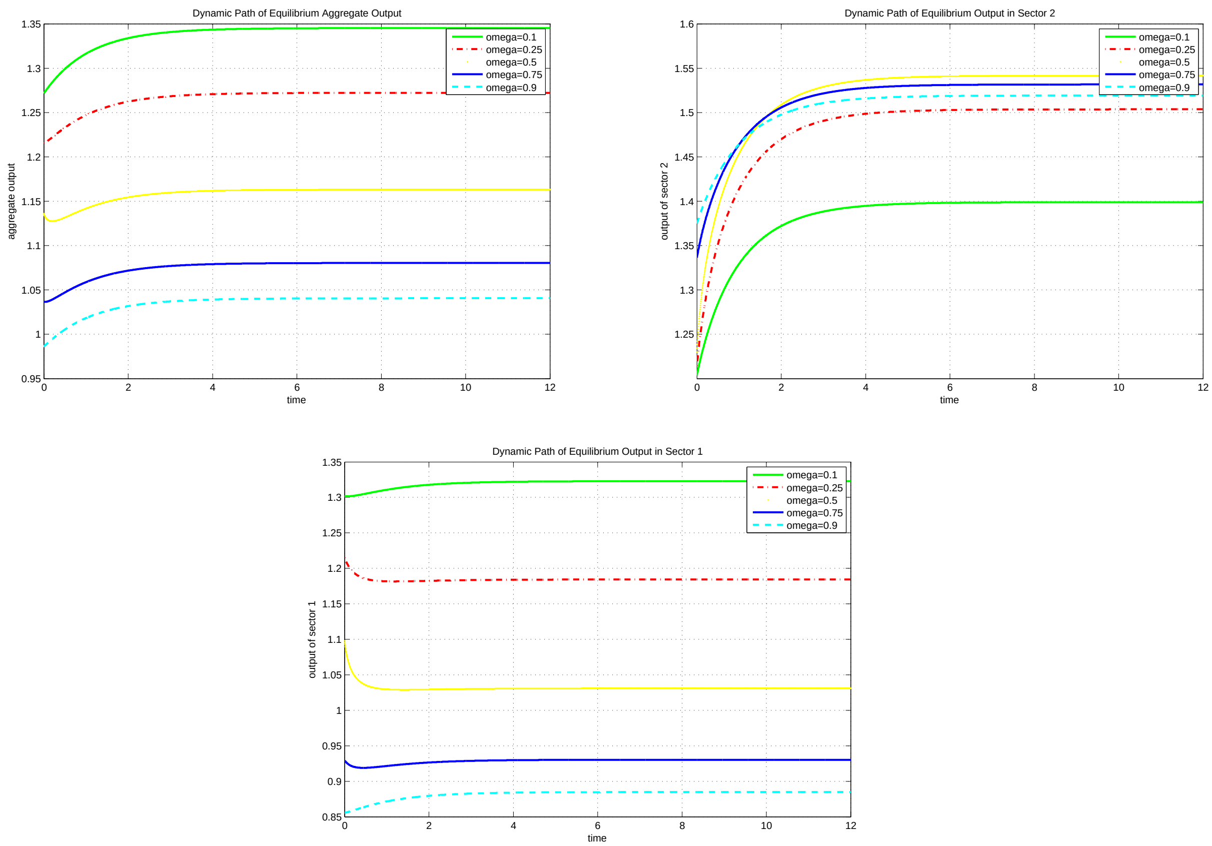


Figure 6: Dynamics of Aggregate and Sectoral Output

The upper right panel of Figure 6 captures the static and dynamic effects of the distortionary industrial policy. On the one hand, the static effect means the output of sector 2 jumps up initially. On the other hand, the dynamic effect implies that $y_2$ grows slower if $\omega$ is larger. The static effect seems dominates when $\omega$ is small. But, eventually, the output of the target sector is smaller if catch-up aspirations become stronger and stronger. As is shown in the bottom panel of Figure 6 , the dynamic behavior of the output of sector 1, $y_1$, is quite similar to that of the aggregate output.[33]

# 6 Conclusion

Due to the popularity of nationalism after World War I, politicians in China, as well as in many developing countries, believed that their nations should give the first priority to the development of advanced capital-intensive industry so as to catching up developed countries as fast as possible. For that purpose, distortionary industrial policies were introduced, leading to a great loss in efficiency and the social welfare.

Our paper develops a two-sector neoclassical growth model with a government who gain utility from not only the social welfare but also the politician's catch-up aspirations. The optimal industrial policy is the solution to the Ramsey allocation problem. We show that the social welfare is lower than that in the first-best equilibrium. After adopting the catch-up industrial policy, the growth of the capital-intensive sector could boost immediately but will lose momentum eventually. If the degree of catch-up aspirations is large enough, even the output of the capital-intensive sector could be lower than that in the first-best equilibrium eventually. Our theoretical predictions are consistent with the growth pattern of China between 1952 to 1978.

[33]The dynamic paths of $k_1$ and $k_2$ are the same as $y_1$ and $y_2$, respectively.

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## Appendix

# A Empirical Framework and Data

**Empirical Framework** Our empirical framework is a variant of the one in Hsieh and Klenow (2009), modified to be consistent with our model in Section 4. There are two sectors (representative firms) that produce two intermediate goods competitively via two Cobb-Douglas production technologies, respectively:

$$y_i = A_i k_i^{\alpha_i} l_i^{1-\alpha_i}, \tag{75}$$

where $i \in \{1, 2\}$ denotes sector $i$ and $\alpha_1 < \alpha_2$. $k_i$ and $l_i$ are capital and labor used in sector $i$. $A_i$ is the sector-level productivity parameter for sector $i$. Denote $p_i$ as the price of the intermediate good $i$. The representative firm in sector $i$ chooses $k_i$ and $l_i$ to maximize the profit:

$$(1-\tau_{yi})\, p_i y_i - (1+\tau_{ki})\, R k_i - (1+\tau_{li})\, W l_i, \tag{76}$$

where $R$ and $W$ are the rental and wage rate. We use the first-order conditions to identify sectoral wedges $\tau_{ji}$, where $j \in \{y, k, l\}$. Notice that only two of the three wedges can be identified:

$$\frac{1+\tau_{ki}}{1-\tau_{yi}} = \alpha_i \left(\frac{p_i y_i}{R k_i}\right),$$

$$\frac{1+\tau_{ki}}{1-\tau_{yi}} = (1-\alpha_i) \left(\frac{p_i y_i}{W l_i}\right).$$

As in Hsieh and Klenow (2009), we use $TFPR_i$ as our measure of sectoral wedges:

$$\begin{aligned} TFPR_i = \frac{p_i y_i}{k_i^{\alpha_i} l_i^{1-\alpha_i}} &= \left(\frac{p_i y_i}{k_i}\right)^{\alpha_i} \left(\frac{p_i y_i}{l_i}\right)^{1-\alpha_i} \\ &= \left(\left(\frac{R}{\alpha_i}\right)\left(\frac{1+\tau_{ki}}{1-\tau_{yi}}\right)\right)^{\alpha_i} \left(\left(\frac{W}{1-\alpha_i}\right)\left(\frac{1+\tau_{li}}{1-\tau_{yi}}\right)\right)^{1-\alpha_i}. \end{aligned}$$

Hence, our measure of the relative wedge is defined by $\frac{TFPR_1}{TFPR_2}$. Due to the data availability, we consider sector 1 and 2 as agriculture and non-agriculture. Empirically, we follow Cheremukhin et al. (2017) and set $\alpha_1 = 0.2$ and $\alpha_2 = 0.3$, although our estimates are very robust with respect to the calibrated value of $\alpha_1$ and $\alpha_2$.

**Data** We use the data of real aggregate and sectoral GDP, sectoral relative prices and wages, sectoral employment, and sectoral real capital from Cheremukhin et al. (2017). The real GDP per capita data are from Groningen Growth and Development Centre (GGDC) database. The heavy and light industry data are from China Compendium of Statistics 1949-1998.

# B Proofs

We first show two useful lemmas. The first one is about how the optimal industrial policy varies when consumption, capital stock and compound variable $z$ change. The second one is a technical result about the endogenous TFP $f(\tau)$. Then we prove Proposition 6 and 7. The result in the lemma will be used in the proof of the two propositions. Finally, we provide and characterize the discrete-time version of our model.

**Lemma 3.** *The optimal subsidy rate $\tau$ is an increasing function of $k$ and $c$, but a decreasing function of $z$ at any time if $\theta = \beta$ holds, that is:*

$$\tau_k' > 0,\ \tau_c' > 0 \ \text{ and } \ \tau_z' < 0. \tag{77}$$

*Proof.* Differentiating the first-order condition (51) derives

$$c\tau_c' \left( \frac{f''(\tau)}{f'(\tau)} + \frac{1-\alpha_2\omega}{1+\tau} \right) = (1-\theta)(1-\omega) > 0, \tag{78}$$

$$k\tau_k' \left( \frac{f''(\tau)}{f'(\tau)} + \frac{1-\alpha_2\omega}{1+\tau} \right) = 1-\alpha_2\omega > 0 \tag{79}$$

and

$$z\tau_z' \left( \frac{f''(\tau)}{f'(\tau)} + \frac{1-\alpha_2\omega}{1+\tau} \right) = -1 < 0. \tag{80}$$

Rearranging the above equations completes the proof. □

**Lemma 4.** $f''(\tau) < 0$. *Let*

$$q(\tau) = \frac{(1+\tau)f'(\tau)}{f(\tau)}, \tag{81}$$

*and*

$$h(\tau) = \left( \frac{(1-\theta)(1-\omega)+\alpha_2\omega}{\alpha_2\omega} \right) q(\tau) + 1 - \beta. \tag{82}$$

*$q(\tau)$ and $h(\tau)$ are decreasing in $\tau$ since both $f'(\tau)$ and $f''(\tau)$ are negative. Moreover, at the steady state, we have*

$$q(\tau^*) = -\frac{\alpha_2\omega}{\alpha_2\omega + (1-\beta)(1-\omega)}, \tag{83}$$

*and*

$$h(\tau^*) = -\beta. \tag{84}$$

*Proof.* Differentiating equation (54) with respect to $\tau$, we obtain

$$\frac{\tau f''(\tau)}{f'(\tau)} = \frac{\alpha_1\gamma + (1-\gamma)(1-\beta)\tau^2}{(1+\tau)(\alpha_1\gamma - (1-\gamma)\tau)} > 0. \tag{85}$$

Hence, $f''(\tau) < 0$ since $f'(\tau) < 0$.Differentiating $q(\tau)$ with respect to $\tau$ yields

$$q'(\tau) = \frac{f'(\tau)}{f(\tau)} \left(1 - \frac{(1+\tau)f'(\tau)}{f(\tau)}\right) + \frac{(1+\tau)f''(\tau)}{f(\tau)}. \tag{86}$$

Both $q'(\tau)$ and $h'(\tau)$ are strictly negative, since $f''(\tau) < 0$ and $f'(\tau) < 0$. Finally, evaluating $q(\tau)$ and $h(\tau)$ at the steady state yields

$$q(\tau^*) = -\frac{\alpha_2\omega}{\alpha_2\omega + (1-\beta)(1-\omega)} < 0, \tag{87}$$

and

$$h(\tau^*) = -\beta < 0. \tag{88}$$

□

**Proof of Proposition 6**

*Proof.* Differentiating the non-linear dynamical system (46), (47) and (74) in the neighborhood of the steady state yields the following linear system:

$$\begin{pmatrix} \dot{c}_h \\ \dot{k}_h \\ \dot{z}_h \end{pmatrix} = N \begin{pmatrix} c_h - c_h^* \\ k_h - k_h^* \\ z_h - z_h^* \end{pmatrix} \tag{89}$$

where $N$ is the Jacobian matrix of the dynamical system evaluated at $c^*$, $k^*$ and $z^*$ and

$$N = \begin{pmatrix} a_{cc} & a_{ck} & a_{cz} \\ a_{kc} & a_{kk} & a_{kz} \\ a_{zc} & a_{zk} & a_{zz} \end{pmatrix} \tag{90}$$

where

$$a_{cc} = Af'(\tau)ck^{\beta-1}\tau_c'|_*, \tag{91}$$

$$a_{ck} = Af'(\tau)ck^{\beta-2}\left(k\tau_k' - \frac{(1-\beta)f(\tau)}{f'(\tau)}\right)|_*, \tag{92}$$

$$a_{cz} = Af'(\tau)ck^{\beta-1}\tau_z'|_*, \tag{93}$$

$$a_{kc} = Af'(\tau)k^{\beta-1}\left(k\tau_c' - \frac{\beta f(\tau)}{\rho f'(\tau)}\right)|_*, \tag{94}$$

$$a_{kk} = Af'(\tau)k^{\beta}\tau_k'|_*, \tag{95}$$

$$a_{kz} = Af'(\tau)k^{\beta}\tau_z'|_*, \tag{96}$$

$$a_{zc} = -z\rho\left(\frac{f'(\tau)}{f(\tau)} + \frac{h'(\tau)}{h(\tau)}\right)\tau_c'|_*, \tag{97}$$

$$a_{zk} = -z\rho\left[\left(\frac{f'(\tau)}{f(\tau)} + \frac{h'(\tau)}{h(\tau)}\right)\tau_k' - \frac{1-\beta}{k}\right]|_*, \tag{98}$$

$$a_{zz} = -z\rho\left(\frac{f'(\tau)}{f(\tau)} + \frac{h'(\tau)}{h(\tau)}\right)\tau_z'|_*, \tag{99}$$

and

$$h(\tau) := \frac{(1-\theta)(1-\omega)+\alpha_2\omega}{\alpha_2\omega} \cdot \frac{(1+\tau)f'(\tau)}{f(\tau)} + 1 - \beta. \tag{100}$$

Let $\lambda_1$, $\lambda_2$ and $\lambda_3$ denote the eigenvalues of the Jacobian matrix $N$. Tedious algebra derives the determinant of $N$ as follows:

$$\frac{\beta(1-\beta)A^2 f^2(\tau)h'(\tau)k^{2\beta-3}zc\tau_z'}{h(\tau)}|_*. \tag{101}$$

Notice that $h'(\tau)$ and $h(\tau)$ are negative at the steady state according to Lemma 4. In addition, Lemma 3 means $\tau_z' < 0$. Therefore, we conclude that $\lambda_1\lambda_2\lambda_3 < 0$. Furthermore, the trace of the Jacobian matrix $N$ is

$$Af'(\tau)k^{\beta-1}\left[c\tau_c' + k\tau_k' + \left(h(\tau) + \frac{f(\tau)h'(\tau)}{f'(\tau)}\right)z\tau_z'\right]|_*. \tag{102}$$

Substituting the results in Lemma (3) into the above equation, we obtain

$$\begin{aligned}\lambda_1+\lambda_2+\lambda_3 =& \frac{Af'(\tau)k^{\beta-1}}{f''(\tau)/f'(\tau) + (1-\alpha_2\omega)/(1+\tau)} \\ &\times\left[(1-\theta)(1-\omega) + 1 + \alpha_2\omega - \beta - h(\tau) - \frac{f(\tau)h'(\tau)}{f'(\tau)}\right]|_*\end{aligned} \tag{103}$$

Notice that

$$h(\tau) + \frac{f(\tau)h'(\tau)}{f'(\tau)} = \left(\frac{(1-\theta)(1-\omega)+\alpha_2\omega}{\alpha_2\omega}\right)\left[1 + \frac{(1+\tau)f''(\tau)}{f'(\tau)}\right] + 1 - \beta, \tag{104}$$

which is obviously strictly greater than $(1-\theta)(1-\omega)+1+\alpha_2\omega-\beta$. It follows that $\lambda_1+\lambda_2+\lambda_3>0$. Therefore, the Jacobian matrix of the linearized dynamic system $N$ has one negative real eigenvalue. The other two eigenvalues have positive real parts. This establishes the existence of a unique saddle path of the dynamical system in the neighborhood of the steady state. □

**Proof of Proposition 7**

*Proof.* In this proof, we first derive a few useful results. Then we prove the proposition in 4 steps. We then rewrite equation (74) as follows:

$$\frac{\dot{z}}{z} = Af(\tau)k^{\beta-1}\left[\frac{(1-\theta)(1-\omega)+\alpha_2\omega}{\alpha_2\omega}\frac{(1+\tau)f'(\tau)}{f(\tau)}+1\right]-\theta\frac{\dot{c}}{c}. \tag{105}$$

In addition, differentiating equation (51) yields the following equation:

$$\left[\frac{\tau(1-\alpha_2\omega)}{1+\tau}+\frac{\tau f''(\tau)}{f'(\tau)}\right]\frac{\dot{\tau}}{\tau} = (1-\theta)(1-\omega)\frac{\dot{c}}{c}+(1+\alpha_2\omega-\beta)\frac{\dot{k}}{k}-\frac{\dot{z}}{z}. \tag{106}$$

Moreover, rewrite equation (74) as below:

$$\frac{\dot{z}}{z} = Af(\tau)k^{\beta-1}(h(\tau)+\beta)-\theta\frac{\dot{c}}{c}. \tag{107}$$

**Step 1.** We first show that the consumption-capital ratio is constant over time during the entire dynamic path. Substituting $\theta=\beta$ into laws of motion of consumption and capital stock (46) and (47) imply

$$\frac{\dot{x}}{x} = x-\frac{\rho}{\beta}. \tag{108}$$

Notice that $x$ converges to $\frac{\rho}{\beta}$ in the long run. This condition plays a role as the boundary condition of the above differential equation. Solving the differential equation and use this boundary implies

$$x=\frac{\rho}{\beta}, \forall t\geq 0. \tag{109}$$

Notice that this result holds not only around the steady state but also along the entire dynamic path.

**Step 2.** We then show that consumption and the capital stock increase over time around the steady state. Notice that the Jacobian matrix of the linearized dynamical system $N$ has only one negative real eigenvalue. Let $\delta$ denote the negative eigenvalue and $v:=[v_1,v_2,v_3]'$ denote the eigenvector associated with $\delta$. Thus, the dynamical system can be rewritten as below:

$$c(t) = (k_0-k^*)\,\frac{v_1}{v_2}e^{\delta t}, \tag{110}$$

$$k(t) = (k_0-k^*)\,e^{\delta t}, \tag{111}$$

and

$$z(t) = (k_0 - k^*)\,\frac{v_3}{v_2} e^{\delta t}, \tag{112}$$

It follows that the capital stock increases over time. Since the consumption-capital ratio is a constant during the entire dynamic path, consumption also increases over time around the steady state.

**Step 3.** We show that the optimal subsidy rate can not be larger than its steady-state value around the steady state: $\tau < \tau^*$. To begin with, suppose at some point $\dot{\tau} \leq 0$. Since $\dot{c} > 0$ and $\dot{k} > 0$, equation (106) implies $h(\tau) + \beta > 0$. Because $h(\tau)$ is decreasing in $\tau$ and $h(\tau^*) + \beta = 0$, we have $\tau < \tau^*$. It follows that $\tau \geq \tau^*$ implies $\dot{\tau} \geq 0$. But this implies that $\tau$ goes to infinity instead of converging to its finite steady state. Therefore, we must have $\tau \leq \tau^*$. The equality holds if and only if the dynamical system is at the steady state. Hence, the optimal subsidy rate $\tau < \tau^*$ along the transitional path to the steady state.

**Step 4.** Last, we prove $\dot{\tau} > 0$ around the steady state. Equation (106), (46) and (105) together with the result in Step 2, imply

$$\left[\frac{\tau(1-\alpha_2\omega)}{1+\tau} + \frac{\tau f''(\tau)}{f'(\tau)}\right]\frac{\dot{\tau}}{\tau} = \frac{My}{k}\left(1 - \frac{q(\tau)}{\alpha_2\omega}\right) - \frac{\rho}{\beta}(M-1). \tag{113}$$

where $M = (1-\theta)(1-\omega) + \alpha_2\omega$. Since $\dot{c} > 0$, we have $\frac{y}{k} > \frac{\rho}{\beta}$. It follows that

$$\left[\frac{\tau(1-\alpha_2\omega)}{1+\tau} + \frac{\tau f''(\tau)}{f'(\tau)}\right]\frac{\dot{\tau}}{\tau} > -\left[1 + \left(1 - \frac{Mq(\tau)}{\alpha_2\omega}\right)\right], \forall \tau. \tag{114}$$

Since the maximum of the right-hand side of the above inequality is 0, we conclude that $\dot{\tau} > 0$ around the steady state.

This completes the proof. □

# C Alternative Industrial Policy

## C.1 No Subsidy on Sector 2

Assume the government also tax sector 2. The tax revenue is given back to the household through a lump-sum transfer. Taking the policy ($\epsilon_0 > 0$ and $\tau_0 > 0$) as given, the representative firm in sector 1 and 2 maximize the profit at each time point:

$$p_1 y_1 - (1+\epsilon_0) r k_1 - w l_1,$$

and

$$p_2 y_2 - (1+\tau_0) r k_2 - w l_2.$$

Let $\tau = \frac{1+\epsilon_0}{1+\tau_0} - 1$. Notice that $\tau > 0$ if and only if $\epsilon_0 > \tau_0$. It is easy to derive the capital and labor allocation across the two sectors as follows:

$$k_1 = \frac{\alpha_1 \gamma}{\beta + \tau \alpha_2 (1-\gamma)} k,$$

$$k_2 = \frac{\alpha_2 (1-\gamma)(1+\tau)}{\beta + \tau \alpha_2 (1-\gamma)} k.$$

Substituting the above equations and the labor allocation (15) and (16) into the sectoral production technology, we rewrite the production function of the two sectors, respectively, as follows:

$$y_1 = A_1 \gamma \left( \frac{\alpha_1}{\alpha_1 \gamma + (1+\tau) \alpha_2 (1-\gamma)} \right)^{\alpha_1} \left( \frac{1-\alpha_1}{1-\beta} \right)^{1-\alpha_1} k^{\alpha_1},$$

and

$$y_2 = A_2 (1-\gamma) \left( \frac{\alpha_2 (1+\tau)}{\alpha_1 \gamma + (1+\tau) \alpha_2 (1-\gamma)} \right)^{\alpha_2} \left( \frac{1-\alpha_2}{1-\beta} \right)^{1-\alpha_2} k^{\alpha_2}.$$

Notice that $y_1$ is strictly decreasing in $\tau$ and $y_2$ is strictly increasing in $\tau$. And then substituting the above sectoral productions into the final good production function (6), it is straightforward to derive:

$$y = \hat{A} \hat{f}(\tau) k^{\beta},$$

where $\hat{A}$ is a constant and $\hat{f}(\tau)$ is the endogenous TFP and is defined as follows:

$$\hat{f}(\tau) = (1+\tau)^{\alpha_2(1-\gamma)} \left( \frac{\beta}{(\beta + \tau \alpha_2 (1-\gamma))} \right)^{\beta}.$$

Notice that $\hat{f}(0) = 1$ and $\tilde{f}(\tau)$ is strictly decreasing in $\tau$. Also notice that $\tau$ is increasing in $\epsilon_0$ and decreasing in $\tau_0$. Hence, a tax reduction in the capital-intensive sector (smaller $\tau_0$) implies a larger $\tau$ and thus a lower measured TFP. Therefore, the theoretical results of our model still hold even if the government subsidizes the capital-intensive sector through tax reduction. More importantly, the definition of $\tau$ above implies that what is essential for our results to hold is the relative sectoral wedge $\frac{1+\epsilon_0}{1+\tau_0}$.

## C.2 Taxing and Subsidizing on Both Sectors

Assume alternatively that the government levies a marginal tax on both capital and labor return in sector 1 while subsidizes both capital and labor return marginally in sector 2. For tractability, we assume the tax (subsidy) rates on capital and labor are identical. The government's budget becomes:

$$\epsilon_0 (rk_1 + wl_1) = \tau_0 (rk_2 + wl_2).$$

This equation equates the total subsidy given to sector 2 to the total tax levied from sector 1.

We show that this alternative industrial policy leads to sectoral and aggregate production functions that are essential identical to those derived in Section 4.4.

Taking the policy ($\epsilon_0$ and $\tau_0$) as given, the representative firm in sector 1 and 2 maximize the profit at each time point:

$$p_1 y_1 - (1+\epsilon_0)(rk_1 + wl_1),$$

and

$$p_2 y_2 - (1-\tau_0)(rk_2 + wl_2).$$

The budget constraint of the government becomes:

$$\epsilon_0 (rk_1 + wl_1) = \tau_0 (rk_2 + wl_2).$$

Substituting conditions (11) and (12) into the above equation derives the relationship between the two rates:

$$\epsilon = \left(\frac{1-\gamma}{\gamma}\right)\tau.$$

To have positive capital input in sector 1, we assume that the subsidy rate is bounded above $\tau < \frac{\gamma}{1-\gamma}$. It is easy to derive the capital and labor allocation across the two sectors as follows:

$$k_1 = \frac{\alpha_1(\gamma - (1-\gamma)\tau)}{\beta + \tau(1-\gamma)(\alpha_2 - \alpha_1)} k,$$

$$l_1 = \frac{(1-\alpha_1)(\gamma - (1-\gamma)\tau)}{1 - \beta - \tau(1-\gamma)(\alpha_2 - \alpha_1)} k,$$

$$k_2 = \frac{\alpha_2(1-\gamma)(1+\tau)}{\beta + \tau(1-\gamma)(\alpha_2 - \alpha_1)} k,$$

$$l_2 = \frac{(1-\alpha_2)(1-\gamma)(1+\tau)}{1 - \beta - \tau(1-\gamma)(\alpha_2 - \alpha_1)} k.$$

Substituting the above equations into the sectoral production technology, we rewrite the production function of the two sectors, respectively, as follows:

$$y_1 = \left[\frac{A_1\gamma\left(\frac{\alpha_1}{\beta}\right)^{\alpha_1}\left(\frac{1-\alpha_1}{1-\beta}\right)^{1-\alpha_1}\left(1-\left(\frac{1-\gamma}{\gamma}\right)\tau\right)}{\left(1+\frac{\tau(1-\gamma)(\alpha_2-\alpha_1)}{\beta}\right)^{\alpha_1}\left(1-\frac{\tau(1-\gamma)(\alpha_2-\alpha_1)}{1-\beta}\right)^{1-\alpha_1}}\right] k^{\alpha_1},$$

and

$$y_2 = \left[\frac{A_2\gamma\left(\frac{\alpha_2}{\beta}\right)^{\alpha_2}\left(\frac{1-\alpha_2}{1-\beta}\right)^{1-\alpha_2}(1-\gamma)(1+\tau)}{\left(1+\frac{\tau(1-\gamma)(\alpha_2-\alpha_1)}{\beta}\right)^{\alpha_2}\left(1-\frac{\tau(1-\gamma)(\alpha_2-\alpha_1)}{1-\beta}\right)^{1-\alpha_2}}\right] k^{\alpha_2}.$$

Notice that $y_1$ is strictly decreasing in $\tau$ and $y_2$ is strictly increasing in $\tau$. And then substituting the above sectoral productions into the final good production function (6), it is straightforward to derive:

$$y = \tilde{A}\tilde{f}(\tau)k^{\beta},$$

where $\tilde{f}(\tau)$ is the endogenous TFP and is defined as follows:

$$\tilde{f}(\tau) = \frac{\left(1-\left(\frac{1-\gamma}{\gamma}\right)\tau\right)^{\gamma}(1+\tau)^{1-\gamma}}{\left(1+\frac{\tau(1-\gamma)(\alpha_2-\alpha_1)}{\beta}\right)^{\beta}\left(1-\frac{\tau(1-\gamma)(\alpha_2-\alpha_1)}{1-\beta}\right)^{1-\beta}},$$

and

$$\tilde{A} = \left(A_1\gamma\left(\frac{\alpha_1}{\beta}\right)^{\alpha_1}\left(\frac{1-\alpha_1}{1-\beta}\right)^{1-\alpha_1}\right)^{\gamma}\left(A_2\left(1-\gamma\right)\left(\frac{\alpha_2}{\beta}\right)^{\alpha_2}\left(\frac{1-\alpha_2}{1-\beta}\right)^{1-\alpha_2}\right)^{1-\gamma}.$$

Notice that $\tilde{f}\left(0\right) = 1$ and $\tilde{f}(\tau)$ is strictly decreasing in $\tau$. Therefore, the sectoral and aggregate production functions qualitatively identical to those in Section 4.4. The rest of the model does not change. Essentially, the alternative industrial policy does not change the theoretical and numerical results in Section 4 and 5.

# D The Discrete-Time Model

We describe the discrete-time version of our continuous-time model in this subsection. We show that the dynamical system in the discrete-time model is saddle-path stable and this result does not depend on the assumption that $\theta = \beta$. We only describe how the discrete-time model differ from the continuous-time model. We assume that time is discrete and the capital fully depreciates period by period. We also assume the utility function of the household takes the logarithmic form: $\log c$ and the discounting factor of time is $\rho$. Therefore, the government essentially maximizes the following utility function:[34]

$$\sum_{t=0}^{\infty}\rho^{t}\left[(1-\omega)\log c_t + \omega\log y_{2,t}\right]. \tag{115}$$

In the competitive equilibrium, the household chooses consumption to maximize

$$\sum_{t=0}^{\infty}\rho^{t}\log c_t. \tag{116}$$

The budget constraint of the household is

$$k_{t+1} = w_t + r_t k_t - c_t. \tag{117}$$

[34]Notice that we do not assume $\theta = \beta$. The purpose of discussing this discrete-time model is to show the robustness all results of our continuous-time model in Section 5. We only show that the discrete-time model is saddle-path stable and the optimal subsidy rate is monotonically increasing over time around the steady state, although most of the results in Section 5 still hold in this discrete-time model.

The setup of the discrete-time model implies it has a closed-form solution. The competitive equilibrium is dictated by the following two policy functions:

$$c_t = (1 - \rho\beta)y_t, \tag{118}$$

and

$$k_{t+1} = \rho\beta y_t, \tag{119}$$

where $y_t = Af(\tau_t)k_t^\beta$. Other endogenous variables at time $t$ are functions of $k_t$, given $\tau_t$. In particular, the output of sector 2 is

$$y_{2,t} = A_2 \left(\frac{\alpha_2(1-\gamma)(1+\tau_t)k_t}{\beta}\right)^{\alpha_2} \left(\frac{(1-\alpha_2)(1-\gamma)}{1-\beta}\right)^{1-\alpha_2}. \tag{120}$$

The Ramsey problem is maximizing utility (115) subject to the two equations, (118) and (119), that dictate the competitive equilibrium. We further assume that $\alpha_1 = \alpha_2 = \beta$ to simplify the notation.[35] Substituting equation (118) and (120) into the utility function of the government, the Ramsey problem becomes essentially maximizing

$$\sum_{t=0}^{\infty} \rho^t (1-\omega)[\log f(\tau_t) + \beta \log k_t] + \omega\beta[\log(1+\tau_t) + \log k_t], \tag{121}$$

subject to the law of motion of the capital stock (119). Solving the Ramsey problem yields the first-order condition:

$$\xi_t = -\frac{1 - \omega + \frac{\beta\omega}{q(\tau_t)}}{\rho\beta Af(\tau_t)k_t^\beta}, \tag{122}$$

and the Euler equation:

$$\xi_t = (\rho\beta)^2 A k_{t+1}^{\beta-1} Q(\tau_{t+1}), \tag{123}$$

where

$$Q(\tau) := \xi(\tau)f(\tau)g(\tau) > 0, \tag{124}$$

$$g(\tau) := 1 - \frac{1}{1 - \omega + \frac{\beta\omega}{q(\tau_{t+1})}} > 0. \tag{125}$$

It is straightforward to show that $Q'(\tau) < 0$ and $g'(\tau) > 0$. The first-order condition means that $\xi$ is a function of $\tau$ (and $\tau$ is also a function of $\xi$). Let $\xi(\tau)$ denote this function. Equation (122) means $\xi'(\tau) < 0$. It is straightforward to show the Ramsey equilibrium has a unique steady state where we have

$$\rho\beta g(\tau^*) = 1. \tag{126}$$

The dynamical system of the Ramsey equilibrium consists of the Euler equation (123) and the law

[35] This assumption will not affect any of our results qualitatitively.

of motion of the capital stock (119). Linearizing the dynamical system around the steady state yields the Jacobian matrix $O$ below:

$$\begin{pmatrix} \beta & O_{12} \\ O_{11} & O_{11} \end{pmatrix} \tag{127}$$

where

$$O_{12} = \frac{f'}{f} k|_*, \tag{128}$$

$$O_{21} = \frac{\beta(1-\beta)}{k\frac{Q'}{Q}}|_*, \tag{129}$$

$$O_{22} = \frac{(1-\beta)\frac{f'}{f} + \frac{\xi'(\tau)}{\xi}}{\frac{Q'(\tau)}{Q}}|_*. \tag{130}$$

To determine the magnitudes of eigenvalues, we first derive the trace and determinant of the Jacobian matrix below:

$$\mathtt{tr}(O) = \beta + \frac{f'}{f} k|_*, \tag{131}$$

$$\mathtt{det}(O) = \frac{\beta\frac{\xi'}{\xi}}{\frac{Q'}{Q}}|_*. \tag{132}$$

It is straightforward to show that

$$1 - \mathtt{tr}(O) + \mathtt{det}(O) = \frac{(1-\beta)\frac{g'}{g}}{\frac{Q'}{Q}}|_* < 0. \tag{133}$$

This implies that one eigenvalue of the Jacobian matrix lies within the unit circle but the other eigenvalue is not. Therefore, the dynamical system is saddle-path stable around the steady state. In addition, the capital stock is monotonically increasing and the optimal subsidy rate is also monotone over time.

In this discrete-time version of our model, the optimal subsidy rate is also monotonically increasing over time. To establish this result, suppose there exists a period $t$ such that $\tau_t > \tau^*$. It follows from the steady state value of $\tau$ that $\rho\beta g(\tau_t) > 1$. Then, equation (122) and (123) imply that

$$\xi(\tau_t) > \rho\beta A k_{t+1}^{\beta-1} \xi_{t+1} f(\tau_{t+1}) = \frac{\xi_{t+1} k_{t+2}}{k_{t+1}} > \xi_{t+1}. \tag{134}$$

It follows from $\xi'(\tau) < 0$ that $\tau_t < \tau_{t+1}$. This means $\tau_t$ will never converges to the steady state which contradicts to our result on the stability of the dynamical system. Hence, we must have $\tau_t < \tau^*$ for any $t$. Then, since $\tau_t$ is monotone, it must be the case that $\tau_t$ is monotonically increasing over time. This completes the proof.