Fiscal stimulus in a global zero lower bound environment

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Abstract

This paper investigates the effect of fiscal stimulus from an emerging market economy perspective. The model captures the significant decline in China's net exports and remarkable quantity of resources that the Chinese government invested into the economy through state-owned enterprises in the aftermath of the 2007-2008 global financial crisis. Our results suggest that fiscal stimulus has played an important role in dampening the economic downturn resulting from the significant decline in exports demand. The state-owned entrepreneur production channel amplifies the multiplier effects of fiscal stimulus and produces a present-value multiplier of 1.6. In a global ZLB environment, fiscal stimulus has a dis-inflationary effect and dampens the expected inflation. Fiscal stimulus improves welfare significantly as a result of much higher household consumption associated with the enhanced multiplier effect. Implementation delays enhance the multiplier effect and the price stabilization effect of fiscal stimulus. It also improves social welfare significantly.

JEL codes: E4, E52, E62, F41, H54

Keywords: Government investment, Fiscal multiplier, Zero nominal interest rate bound, Emerging market economies

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1 Introduction

During the recent global financial crisis, the Chinese economy experienced a significant decline in net exports – it fell nearly 50 percent from 2007 to 2009. Despite the severe decline in exports, the economy recovered quickly – the annual growth rate of gross domestic product (GDP) reached double digits again in 2010 (see Figure 1). At the same time, other major economies, such as the U.S., the EU and Japan were still suffering from the Great Recession (IMF, 2010). China's rapid recovery has been regarded as a great success of fiscal stimulus programs introduced by the government during and after the crisis, as China's economic growth relied heavily on exports before the crisis.[1]

In November 2008, the State Council of China announced a 4 trillion renminbi stimulus package as an attempt to battle the global financial crisis and its negative impact on economic growth. Funds are mainly distributed to public infrastructure development, including reconstruction works in Sichuan province, the region hit by the earthquake in May 2008. A significant amount of funds (370 billion renminbi) is also allocated to technology advancement programs in helping the economic transition from export-oriented growth to a more balanced economic growth. This implies that state-owned enterprises (SOEs) receive a significant amount of investment from the government (NDRC, 2009). The stimulus package seems to have been more successful than expected as China's economic growth returned back to 10 percent in 2010 (IMF, 2010).

Although there is a general consensus that government spending is ideal for counteracting recessions, the effectiveness of such countercyclical tools remains unclear. This is reflected by the wide range of estimated fiscal multipliers. Theoretical literature suggests a spending multiplier around 1 during normal times (see, Hall, 2009), while it can increase more than 3 times when the zero lower bound (ZLB) on nominal interest rate is binding (see, Christiano et al., 2011; Eggertsson, 2011).[2] Under ZLB, government spending increases aggregate demand and, at the same time, it increases the expected inflation, resulting in negative real interest rate. The negative real interest rate encourages investment and, hence, the economy recovers at a rapid pace. This increases the government spending multiplier under ZLB

[1]Exports account for roughly 34 percent of China's GDP before the crisis (own calculation).

[2]The value of the spending multiplier depends on the underlying assumptions, such as the definition of government spending (consumption or investment) and the type of multiplier it refers to. In the empirical literature, it also varies depending on the time horizons. These are, however, beyond the scope of the current study.

(liquidity trap).

This paper is related to a number of recent studies that investigate government spending and fiscal stimulus in a liquidity trap (see, e.g., Christiano et al., 2011; Eggertsson, 2011; Woodford, 2011; Erceg and Linde, 2014; Bouakez et al., 2016). During the Great Recession, most major economies implemented fiscal stimulus to help the economy to recover quicker, given that monetary policy became ineffective due to the binding ZLB. For instants, the U.S. Congress passed several fiscal stimulus bills in 2009, including the 787 billion U.S. dollar American Recovery and Reinvestment Act (ARRA). Overall, these studies suggest that the spending multiplier can be much larger in a liquidity trap than that during normal times. Some of the studies also focus on fiscal stimulus implementation delays (see, e.g., Leeper et al., 2010; Erceg and Linde, 2014; Bouakez et al., 2016). For instants, Leeper et al. (2010) argue that, in the short run, implementation delay can significantly dampen the multiplier effect, even producing negative effects on labor and output. All these studies are in the context of close economy, and focus on the U.S. economy.

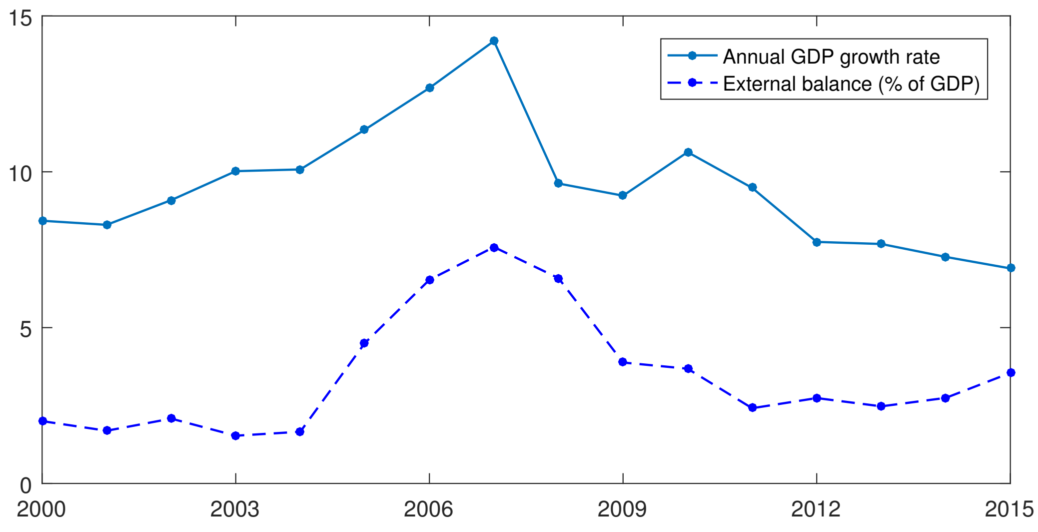

Figure 1: Annual growth rate of GDP in percentage for China (solid-dotted line), and China's external balance on goods and services expressed in percentages of GDP (dashed-dotted line). Source: World development indicators, World Bank.

Wen and Wu (2014) develop a dynamic general equilibrium model to investigate the transmission mechanisms through which fiscal stimulus assisted China's economy to recover during the Great Recession. The authors also use the model to explain why China's economic growth was sustained with such stimulus, while other major economies were suffering deeply during the Great Recession, despite implementing similar stimulus programs. In the model, stimulus programs are implicitly implemented through SOEs, which is consistent with the data that there is a dramatic switch in gross fixed capital formation from private-owned enterprises (POEs) to SOEs during the Great Recession. Liquidity trap is generated through the increase in fixed production cost. In facing a significant increase in fixed production cost, POEs are forced to shut down if their revenue can no longer cover costs, while SOEs are still able to continue their production as the Chinese Government wants to implement its stimulus programs through the SOEs.

This paper studies the effectiveness of China's fiscal stimulus when foreign monetary policy rate is under normal times and at ZLB, and the impact of implementation delays for government investment. To do so, we extend the standard medium-scale New Keynesian model into an open economy model and augment an additional SOE-production sector to capture the characteristics of the Chinese economy. Analogous to households investing in POEs, SOEs' physical capital is accumulated with government investment. Thus, government implements stimulus programs by investing in SOEs. This is in line with the significant increase in the annual growth rate of gross fixed capital formation in SOEs from 11.59 percent in 2008Q2 to 45.3 percent in 2009Q2 (Wen and Wu, 2014). Following Leeper et al. (2010) and Bouakez et al. (2016), we focus on government investment as apposed to the entirely wasteful government consumption in the literature. Since it takes time for government investment to produce the multiplier effects, it is necessary to investigate the impact of implementation delays when studying the multiplier effect of fiscal stimulus. We model implementation delays by assuming government investment with lags, along the lines of Uhlig (2010) and Erceg and Linde (2014).

We use a large size of negative exports demand shock to create global ZLB environment. This is contrast to Christiano, Eichenbaum, and Rebelo (2011), Erceg and Linde (2014), Eggertsson (2011), Woodford (2011) and Erceg and Linde (2014), in which a large size of preference shock drives domestic monetary policy rate to ZLB. A large negative exports demand shock not only creates global ZLB environment, but also mimics what China experienced during the Great Recession – a nearly 50 percent decrease of net exports hit the export-oriented economy severely during the Great Recession. At the same time, while the global economy is experiencing liquidity trap, the Chinese domestic monetary policy rate remained way above zero. This provides a more meaningful framework for investigating the effectiveness of China's fiscal stimulus in a global ZLB environment.

This paper contributes to the existing literature from various dimensions. First, according to the authors' knowledge, this is the first to study the effectiveness of China's fiscal stimulus in a global ZLB environment. That is, in contrast to the existing literature focusing on developed economy (mainly the U.S. economy), this paper focuses on the largest emerging market economy. Subsequently, the second contribution of the paper is that it is the first study on ZLB topic in the context of open economy. Lastly, from modelling perspective, the model explicitly captures how stimulus programs are implemented in China and a number of characteristics of the Chinese economy. Specifically, we introduce an additional type of enterprises, namely SOEs, to model the channel through which the Chinese government implemented stimulus programs during the Great Recession and, at the same time, it mimics the market structure of the Chinese economy. Given that China's economic growth relied heavily on exports before the current crisis and it is the dramatic decline in exports that dragged the economy down during the Great Recession, we make use of a negative exports demand shock to create global ZLB environment.

Our results show that through the SOE production channel, government investment amplifies the multiplier effects and produces a present-value multiplier of 1.6. An increment in government investment acts as a positive productive shock and increases the SOE intermediate goods production and, hence, the final goods production. The SOE production channel also produces a spill-over effect on the POE production, which increases the final goods production further. Fiscal stimulus has a dis-inflationary effect and dampens the expected inflation.

Implementation delays enhance the multiplier effects of fiscal stimulus. With a moderate period of implementation delays (4 quarters), this amplification effect tends to be more persistent, whereas with 8 quarters delays, the amplification effect starts to diminish 20 quarters after the shock occurs. Implementation delays produce a stronger positive impact on household consumption and, at the same time, it attenuates the dis-inflationary effect of fiscal stimulus. Compared to the scenario where there is no implementation delays, household consumption increases slightly more with 4-quarter implementation delays. This increase becomes more visible when fiscal stimulus is only fully implemented with 8-quarter lag.

Implementation delays also produce a price stabilization effect: inflation decreases much less when fiscal stimulus is implemented with lags. This effect becomes more significant when delays are longer. With a longer period of implementation delays, since it takes longer time to build public capital, the positive productivity effect associated with fiscal stimulus gradually attenuates inflation. A subsequent effect of this price stabilization is that it allows monetary authority to adjust its policy rate moderately, as opposed to the sharp decrease required when there are no implementation delays.

Fiscal stimulus improves social welfare. Recall that household consumption increases following the implementation of fiscal stimulus. The dis-inflationary effect of fiscal stimulus increases household consumption further. Under the global ZLB, welfare increases significantly as a result of much higher household consumption associated with the enhanced multiplier effect. Implementation delays improves social welfare even further.

The remainder of the paper is structured as follows. Section 2 describes the model setup. Section 3 presents parameter values and Section 4 discusses the results. Section 5 concludes.

2 The model

We develop an open economy New Keynesian model and augment the model with SOEs to account for the existence of private- and state- owned enterprises in China. More importantly, it mimics the channel through which the Chinese government implemented stimulus programs to counteract the significant economic slowdown during the Great Recession. In contrast to Leeper et al. (2010) and and Bouakez et al. (2016), where public capital is accumulated by government investment and enters into the production directly either as an additional type of capital or as the only type of capital, we assume that government invests in SOEs and households invest in POEs, respectively.

In addition to renting government investment to SOEs, government issues bonds to households and obtain taxes from consumption and labor wage income. In the model, we assume government also invests in foreign government bonds. This mimics the significant amount of foreign exchange reserves held by the Chinese government. The domestic monetary policy follows a standard Taylor type rule. Following Chang et al. (2015), we assume the demand for exports is exogenously determined, depending negatively on the relative price of home goods to foreign goods.

The basic framework of the model is a standard medium-scale New Keynesian model, inhabited by households, intermediate good producers, and a retailer. Households consume final goods, supply labor to both types of enterprises, hold government bonds, and invest in POEs. Both types of enterprises use capital and labor to produce intermediate goods. The retailer produces final goods using intermediate goods produced by both POEs and SOEs, and imported goods. Part of final goods are consumed by households and government and the rest are exported.

2.1 Households

Households consume final goods, C_t, acquire government bonds, B_t, supply labor to both types of enterprises, L_t (in aggregation), and invest in POE capital, I_t^p. The representative household maximizes her expected life time utility:

$$W_0 = \sum_{t=0}^{\infty} \beta^t \left[\ln\left(C_t - hC_{t-1}\right) + \gamma \ln\left(1 - L_t\right)\right], \tag{1}$$

subject to the budget constraint and the law of motion for POE capital, K_t^p:

$$B_t + \left(1 + \tau_c\right) C_t + I_t^p = \frac{R_{t-1} B_{t-1}}{\pi_t} + r_{t-1}^{k,p} K_{t-1}^p + \left(1 - \tau_l\right) W_t L_t + \Psi_t^r + Z_t, \tag{2}$$

$$K_t^p = \left(1 - \delta\right) K_{t-1}^p + \left(1 - \Omega_t^p\right) I_t^p, \tag{3}$$

where $h, \gamma, \tau_c, \tau_l, \delta \in (0,1)$ represent the habit persistence parameter, leisure utility parameter, tax rate on consumption, tax rate on wage income, and the depreciation rate of private capital, respectively. R_t is the gross nominal rate of government bonds, which is equivalent to domestic monetary policy rate. $r_t^{k,p}$ is the rate of return to private capital and W_t is the wage rate. Inflation is defined as $\pi_t \equiv P_t / P_{t-1}$, where P_t is the price of consumption goods. Households receive dividend payments from retailers (Ψ_t^r) and a lump sum transfer from government (Z_t). The adjustment cost of private investment $\Omega_t^p \equiv \left(\Omega_p/2\right)\left[\left(I_t^p/I_{t-1}^p\right) - 1\right]^2$.

Defining λ_t and λ_t^k as Lagrange multipliers of constraints (2) and (3), the first order conditions are:

$$\lambda_t = \beta\lambda_{t+1}R_t/\pi_{t+1}, \tag{4}$$

$$\left(C_t - hC_{t-1}\right)^{-1} - \beta h\left(C_{t+1} - hC_t\right)^{-1} = (1+\tau_c)\,\lambda_t, \tag{5}$$

$$\lambda_t = \lambda_t^k\left[1 - \Omega_t^p - \Omega_t^{p'}I_t^p\right] - \beta\lambda_{t+1}^k\Omega_{t+1}^{p'}I_{t+1}^p, \tag{6}$$

$$\lambda_t^k = \beta\left[\lambda_{t+1}r_t^{k,p} + \lambda_{t+1}^k(1-\delta)\right], \tag{7}$$

$$(1-\tau_l)\,\lambda_t W_t = \gamma\,(1-L_t)^{-1}. \tag{8}$$

Equation 4 gives the optimal condition for holding government bonds, and Equation 5 is the consumption Euler equation. Equation 6 and Equation 7 give the optimal decision for investing in private capital. Equation 8 gives the optimal labor supply decision.

2.2 Private-owned enterprises (POEs)

The representative POE produces intermediate good, $Y_{j,t}^p$, with a Cobb-Douglas functional form with the inputs of labor, $L_{j,t}^p$, and private capital from households, $K_{j,t}^p$:

$$Y_{j,t}^p = \left(L_{j,t}^p\right)^{\alpha_p}\left(K_{j,t-1}^p\right)^{1-\alpha_p}, \tag{9}$$

where $\alpha_p \in (0,1)$ is the labor-output share for POEs.

The representative POE maximizes her profits:

$$\sum_{t=0}^{\infty}\Lambda_t\Psi_{j,t}^p, \tag{10}$$

subject to the production constraint (9) and the following constraint:

$$\Psi_{j,t}^p = Q_{j,t}^p Y_{j,t}^p - W_t L_{j,t}^p - r_{t-1}^{k,p}K_{j,t-1}^p, \tag{11}$$

where $Q_{j,t}^p$ is the relative price of POE intermediate goods to final goods and Λ_t is the stochastic discount factor, $\Lambda_t \equiv \beta\lambda_{t+1}/\lambda_t$.

The first order conditions below give the optimal return to capital (12) and POE labor market equilibrium condition (13), respectively:

$$r_t^{k,p} = \left(1 - \alpha_p\right) Q_{j,t+1}^p Y_{j,t+1}^p / K_{j,t}^p, \tag{12}$$

$$W_t = \alpha_p Q_{j,t}^p Y_{j,t}^p / L_{j,t}^p. \tag{13}$$

2.3 State-owned enterprises (SOEs)

Analogously, the representative SOE produces intermediate good, $Y_{j,t}^s$, with a Cobb-Douglas functional form with the inputs of labor, $L_{j,t}^s$, and public capital from government, $K_{j,t}^s$:

$$Y_{j,t}^s = \left(L_{j,t}^s\right)^{\alpha_s} \left(K_{j,t-1}^s\right)^{1-\alpha_s}, \tag{14}$$

where $\alpha_s \in (0,1)$ is the labor-output share for SOEs.

The representative SOE maximizes her profits:

$$\sum_{t=0}^{\infty} \Lambda_t \Psi_{j,t}^s, \tag{15}$$

subject to the production constraint (14) and the following constraint:

$$\Psi_{j,t}^s = Q_{j,t}^s Y_{j,t}^s - W_t L_{j,t}^s - r_{t-1}^{k,s} K_{j,t-1}^s, \tag{16}$$

where $Q_{j,t}^s$ is the relative price of SOE intermediate goods to final goods, and $r_t^{k,s}$ is the rate of return to public capital.

The first order conditions below give the optimal return to capital (17) and SOE labor market equilibrium condition (18), respectively:

$$r_t^{k,s} = (1 - \alpha_s) Q_{j,t+1}^s Y_{j,t+1}^s / K_{j,t}^s, \tag{17}$$

$$W_t = \alpha_s Q_{j,t}^s Y_{j,t}^s / L_{j,t}^s. \tag{18}$$

2.4 Retailers

The representative retailer produces final goods, $Y_{j,t}$, using imported goods, $X_{j,t}^i$, and intermediate goods produced by the POEs and the SOEs. The production technology is defined as follows:

$$Y_{j,t} = \left(X^i_{j,t}\right)^{\alpha^i_r} \left(Y^p_{j,t}\right)^{\alpha^p_r} \left(Y^s_{j,t}\right)^{1-\alpha^i_r-\alpha^p_r}, \tag{19}$$

where $\alpha^i_r, \alpha^p_r \in (0,1)$ are the shares of imported goods and POE-produced intermediate goods related to the production of final goods, respectively.

Retailers operate in a monopolistically competitive market, choosing price $P_{j,t}$ to maximize their profits ($\Psi^r_{j,t}$):

$$\sum_{t=0}^{\infty} \Lambda_t \left[\left(P_{j,t}/P_t\right) Y_{j,t} - Q^p_t Y^p_{j,t} - Q^s_t Y^s_{j,t} - S_t X^i_{j,t} - \Omega^r_t C_t\right], \tag{20}$$

subject to:

$$Y_{j,t} = \left(P_{j,t}/P_t\right)^{-\epsilon} Y_t. \tag{21}$$

ϵ is the price elasticity of demand for $Y_{j,t}$. The real exchange rate is denoted by $S_t \equiv e_t P^*_t / P_t$.

Following Rotemberg (1982), we assume retailers can adjust their prices in each period, subject to a quadratic cost $\Omega^r_t \equiv (\Omega_r/2)\left[\left(P_{j,t}/\pi P_{j,t-1}\right) - 1\right]^2$.

Defining λ^r_t as the Lagrange multiplier of (21), the first order conditions are:

$$X^i_{j,t} = \alpha^i_r \lambda^r_t P_{j,t} Y_{j,t} / P_t S_t, \tag{22}$$

$$Y^p_{j,t} = \alpha^p_r \lambda^r_t P_{j,t} Y_{j,t} / P_t Q^p_t, \tag{23}$$

$$Y^s_{j,t} = \left(1 - \alpha^i_r - \alpha^p_r\right) \lambda^r_t P_{j,t} Y_{j,t} / P_t Q^s_t. \tag{24}$$

Equation 22 gives the optimal demand for imports, which is decreasing in real exchange rate and increasing in final good production. Equations 23 and 24 are the demand functions for POE-produced and SOE-produced intermediate goods, respectively.

2.5 Government

The government invests in public capital, and consumes consumption goods, G_t. In addition, the government invests in foreign government bonds, B^*_t. All expenditures are financed through taxes and issuing domestic government bonds. The budget constraint of the government is as follows:

$$S_t B_t^* + G_t + I_t^g + \frac{R_{t-1} B_{t-1}}{\pi_t} + Z_t = B_t + S_t (1 - \tau_b) R_{t-1}^* B_{t-1}^* + \tau_c C_t + \tau_l W_t L_t + r_{t-1}^{k,s} K_{t-1}^g, \quad (25)$$

where I_t^g represents government investment in public capital, G_t represents government consumption expenditure, and Z_t represents the lump sum transfer to households as explained previously.[3] R_t^* is the return to foreign government bonds, which is equivalent to the foreign monetary policy rate in the model. We assume there is an additional cost involved in holding foreign government bonds, which is captured by parameter τ_b. It serves as a technical device to assure trade balance and foreign government bonds to GDP ratio matching those observed from the data.

The evolution of public capital is defined as follows:

$$K_t^g = (1 - \delta) K_{t-1}^g + (1 - \Omega_t^g) I_t^g. \quad (26)$$

Following the literature, similar to private capital accumulation, we assume government investment is subject to quadratic adjustment costs. However, we assume that government investment carries a higher adjustment cost. That is, $\Omega_t^g \equiv \left(\Omega_g/2\right) \left[\left(I_t^g/I_{t-1}^g\right) - 1\right]^2$, and $\Omega_g > \Omega_p$, which implies that government investment is less efficient than private investment.

Government investment follows an AR(1) process:

$$\log (I_t^g) = \rho_i \log (I^g) + (1 - \rho_i) \log \left(I_{t-1}^g\right) + \xi_{i,t}, \quad \xi_{i,t} \sim (0, \sigma_i). \quad (27)$$

Domestic monetary policy follows a Taylor-type rule:

$$R_t = R \left(GDP_t/GDP\right)^{\theta_{gdp}} \left(\pi_t/\pi\right)^{\theta_\pi}, \quad (28)$$

where θ_{gdp}, θ_π are the parameters corresponding to GDP and inflation (deviation from its steady state), respectively.

[3] For simplicity, government consumption and transfers are defined as a fraction of GDP: $G_t = \omega_g GDP_t$ and $Z_t = \omega_z GDP_t$, respectively.

Following the expenditure approach, GDP_t, is defined as follows:

$$GDP_t \equiv C_t + G_t + I_t^p + I_t^g + X_t^e - S_t X_t^i, \tag{29}$$

where X_t^e is the foreign demand for exports, and is defined exogenously:

$$X_t^e = [P_t / (e_t P_t^*)]^{-\epsilon_\chi} \chi_t = (S_t)^{\epsilon_\chi} \chi_t. \tag{30}$$

Exports depend positively on the real exchange rate, and the exports demand shock follows an AR(1) process:

$$\log(\chi_t) = \rho_\chi \log(\chi) + \left(1 - \rho_\chi\right) \log(\chi_{t-1}) + \xi_{\chi,t}, \quad \sim (0, \sigma_\chi). \tag{31}$$

2.6 Foreign sector

The home economy imports intermediate goods and exports final goods, and the domestic government invests in foreign government bonds. In equilibrium, trade balance equals to home economy's net capital flows:

$$X_t^e - S_t X_t^i \equiv S_t B_t^* - S_t (1 - \tau_b) R_{t-1}^* B_{t-1}^*. \tag{32}$$

The current account, CA_t, is defined as the change in home economy's net foreign asset position:

$$CA_t \equiv S_t \left(B_t^* - B_{t-1}^*\right). \tag{33}$$

Current account surplus (deficit) is associated with an increase (decrease) in home economy's foreign assets.

Following Schmitt-Grohe and Uribe (2003), we define foreign monetary policy as follows:

$$R_t^* = R^* + \Omega_t^b, \tag{34}$$

where R^* is the equilibrium foreign monetary policy rate. Ω_t^b is the risk premium that evolves according to the level of debt in the foreign economy, i.e., $\Omega_t^b \equiv \Omega_b \left[\exp(B_t^* - B^*) - 1\right]$. It states that the risk premium is positively related to the level of foreign government bonds.[4]

2.7 Market clearing and symmetric equilibrium

The market clearing condition for total final goods is given by:

$$Y_t = C_t + G_t + I_t^p + I_t^g + X_t^e + \Omega_t, \tag{35}$$

where Ω_t is the sum of aggregate adjustment costs, $\Omega_t = \Omega_t^g + \Omega_t^p + \Omega_t^r$.

In a symmetric equilibrium, labor supply is aggregated as follows:

$$L_t^p = \int L_{j,t}^p dj, \quad L_t^s = \int L_{j,t}^s dj, \tag{36}$$

and the total supply of labor for both POEs and SOEs is:

$$L_t = L_t^p + L_t^s. \tag{37}$$

In a symmetric equilibrium, we have aggregated private and public capital $K_t^p = \int K_{j,t}^p dj$ and $K_t^g = \int K_{j,t}^g dj$, respectively. $Y_t^p = \int Y_{j,t}^p dj$ and $Y_t^s = \int Y_{j,t}^s dj$ are the aggregated POE- and SOE-produced intermediate goods, whereby $Y_t = \int Y_{j,t} dj$ are the aggregated final goods. Aggregate profits from POEs, SOEs, and retailers are $\Psi_t^p = \int \Psi_{j,t}^p dj$, $\Psi_t^s = \int \Psi_{j,t}^s dj$, and $\Psi_t^r = \int \Psi_{j,t}^r dj$, respectively.

In a symmetric equilibrium, the optimal price condition is reduced to the following:

$$\epsilon \lambda_t^r = (\epsilon - 1) + (\Omega_r / Y_t) \left\{ \left[(\pi_t / \pi) - 1 \right] (C_t \pi_t / \pi) - \left(\Lambda_{t+1} / \Lambda_t \right) \left[\left(\pi_{t+1} / \pi \right) - 1 \right] \left(C_{t+1} \pi_{t+1} / \pi \right) \right\}. \tag{38}$$

3 Parametrization

We calibrate the model to mimic what the Chinese economy experienced during the current financial crisis. Table 1 summarizes the parameters values and Table 2 presents the targeted steady-state ratios.

[4] B^* is the steady-state level of foreign government bonds and Ω_b is the parameter that captures the size of the premium.

The discount parameter is set to $\beta = 0.99$, such that the annualized return to domestic government bonds is 4%. This implies that the domestic monetary policy rate is in line with the average Shanghai Interbank Offered Rate (SHIBOR) over the period 2007-2013. The steady-state foreign monetary policy rate, R^*, is assumed to be 1% (annualized), which is about the average U.S. Federal funds rate during the current financial crisis. We assume both private and public capital depreciate at 2.5% quarterly, or 10% annually, which is commonly found in the literature. The elasticity of substitution between intermediate goods, ϵ, and the elasticity of demand for exports, ϵ_χ, are set to 10 and 1.5, respectively (see, Chang et al., 2015). The utility parameter for leisure is set to $\gamma = 1.1161$, so that total labor supply is 30%. The habit persistence, h, is set to 0.55. In steady state, inflation rate, nominal exchange rate and real exchange rate are equal to 1, $\pi = e = S = 1$, so as the law of one price holds, $P = P^*$.

As discussed in previous section, we assume that public capital is less efficient than private capital and this is achieved by calibrating the adjustment-cost parameter for government investment $\Omega_g = 0.50$, which is greater than that of private investment $\Omega_p = 0.25$. The parameter that governs the quadratic adjustment cost for price setting is set to $\Omega_r = 60$, which implies, on average, retailers can adjust prices every four quarters Chang et al. (2015).

Parameters related to GDP and inflation deviations in the domestic monetary policy rule are set to $\theta_{gdp} = 0.015$ and $\theta_\pi = 1.01$, respectively. These values are consistent with the estimates found in the literature for the Chinese economy (e.g., Zhang, 2009; Mehrotra, Nuutilainen, and Pääkkönen, 2013). The persistence parameters for government investment shock and exports demand shock are set to $\rho_i = 0.85$ and $\rho_\chi = 0.75$, respectively. The parameter that governs the size of risk premium is set to $\Omega_b = 0.0485$, such that, given the size of the shock, foreign monetary policy rate reaches ZLB and lasts for eight periods.

The POE and SOE labor shares in production, α_p and α_s are computed as follows. For simplicity, we assume that both wage rates and the supply of labor for both types of enterprises are the same. Using the optimal labor supply conditions, we have $\alpha_p = 0.3812$ and $\alpha_s = 0.3351$.[5] The share of imports in retailers' production is derived using the market clearing condition (35) and the definition of GDP (29), $\alpha_r^i = 0.2362$.[6] Using Equation 23, we obtain the share of POE-produced intermediate goods in retailers' production, $\alpha_r^p =$

[5]See Appendix B.1 for more details.
[6]See Appendix B.2 for more details.

Table 1: Parameter values.

Parameter	Value	Description
β	0.99	Discount factor
δ	0.025	Depreciation rate of capital
ϵ	10	Elasticity of substitution between intermediate goods
ϵ_χ	1.5	Elasticity of exports demand
γ	1.1161	Utility weight on leisure
h	0.55	Habit formation
Ω_g	0.50	Adjustment cost of government investment
Ω_p	0.25	Adjustment cost of household investment
Ω_r	60	Adjustment cost of price setting
ρ_i	0.85	Persistence of government investment shock
ρ_χ	0.75	Persistence of exports demand shock
θ_{gdp}	0.015	Parameter related to GDP deviation
θ_π	1.01	Parameter related to inflation deviation
Ω_b	0.0485	Risk premium parameter
α_p	0.3812	POEs labor share
α_s	0.3351	SOEs labor share
α_r^i	0.2362	Share of imports
α_r^p	0.3573	Share of POE-produced intermediate googs
τ_b	0.1771	External costs of holding foreign assets
τ_c	0.1530	Consumption tax rate
τ_l	0.30	Labor income tax rate

Table 2: Steady state ratios.

Main ratios		Value
Gross Domestic Product composition		
Household consumption	C/GDP	0.40
Government consumption	G/GDP	0.13
Total investment	$(I^p + I^g)/GDP$	0.40
Household investment	I^p/GDP	0.18
Government investment	I^g/GDP	0.22
Net exports	$(X^e - SX^i)/GDP$	0.07
Exports	X^e/GDP	0.34
Imports	X^i/GDP	0.27
Others		
Bonds	B/GDP	0.35
Foreign bonds	B^*/GDP	0.40
Transfers	Z/GDP	0.04

0.3573. Correspondingly, we have the share of SOE-produced intermediate goods in retailers' production, $1 - \alpha_r^i - \alpha_r^p = 0.4065$.

To compute taxes rates on consumption and wage income, we make use households' budget constraint (2) and government's budget constraint (25), and the targeted steady-state ratios. Consumption tax rate $\tau_c = 0.1533$, whereby wage income tax rate $\tau_l = 0.30$.[7] Lastly, we make use of trade balance (32) and the targeted steady-state ratios of net exports to GDP and foreign government bonds holding to GDP to obtain $\tau_b = 0.1771$.[8]

In Table 2, we provide the targeted steady-state ratios that match those observed from the Chinese data during the current financial crisis. Household consumption to GDP and government consumption expenditure to GDP ratios are calibrated to 0.4 and 0.13, respectively. The ratios of Household investment and government investment to GDP are 0.18 and 0.22, respectively. The steady state ratio of imports to GDP is 0.27, whereby that of exports is 0.34, such that the net exports to GPD ratio is 0.07. The ratio of domestic government bonds to GPD is 0.35 and that of foreign government bonds is 0.4. Lastly, the total transfers to GDP is assumed to be 4%.

[7]See Appendix B.3 for more details.
[8]See Appendix B.4 for more details.

4 Analysis

In this section, we first investigate the effectiveness of China's fiscal stimulus in a global ZLB environment, compared to normal times. We then study the effect of implementation delays for fiscal stimulus and the fiscal multipliers associated with the stimulus in a global ZLB. To complement our study, we report the welfare implications of fiscal stimulus.

4.1 Exports crunch, fiscal stimulus and zero lower bound

To replicate the significant decline in exports that the Chinese economy experienced during the recent crisis, we simulate the model with a 25% decrease in exports, which is equivalent to approximately 50% decrease in net exports.[9] Fiscal stimulus is captured by a positive government investment shock in our simulation analysis.

While the Chinese government implemented fiscal stimulus, foreign monetary policy rates, such as the U.S. FED funds rate, were binding at ZLB. To replicate the global ZLB, we modify the foreign monetary policy Equation 34 as follows:

$$R_t^* = \max\left(1, R^* + \Omega_t^b\right), \tag{39}$$

where foreign monetary policy rate is binding at ZLB when R_t^* equals to 1. In the experiment, we choose the parameter that governs the size of the risk premium $\omega_b = 0.0485$, such that the foreign monetary policy rate reaches ZLB and lasts for eight periods.

Figure 2 plots the impulse response functions (IRFs) of the main variables following a positive government investment shock, under the global ZLB (dashed-dotted line) and normal times (dashed line). Under normal times, the size of the negative exports shock is 1%. For comparison purpose, Figure 2 also plots the IRFs of the main variables under the global ZLB when there is no fiscal stimulus in place (solid-dotted line) and that under normal times (solid line).

Under both normal times and the global ZLB, the negative aggregate demand shock (exports shock) results in a decrease in output and inflation. Following the Taylor rule, the monetary authority adjusts its policy rate accordingly, where we see a decline in the domestic

[9] The external balance on goods and services in percentage of GDP fell about 50 percent during the current crisis.

policy rate. The fall in the interest rate discourages households' investment and increases consumption.

Compared to normal times, the IRFs under the global ZLB are much stronger. With a 25% decrease in exports, trade balance shrinks sharply. This forces the domestic government to decrease the foreign government bond holdings (current account decreases), resulting the FED funds rate to fall significantly and reach ZLB. The shock causes a 4% decline in output, which mimics the significant drop in output growth observed from the data. Domestic policy rate decreases more in response to the severe decline in output and inflation, resulting in a significant decrease in domestic government bond holdings.

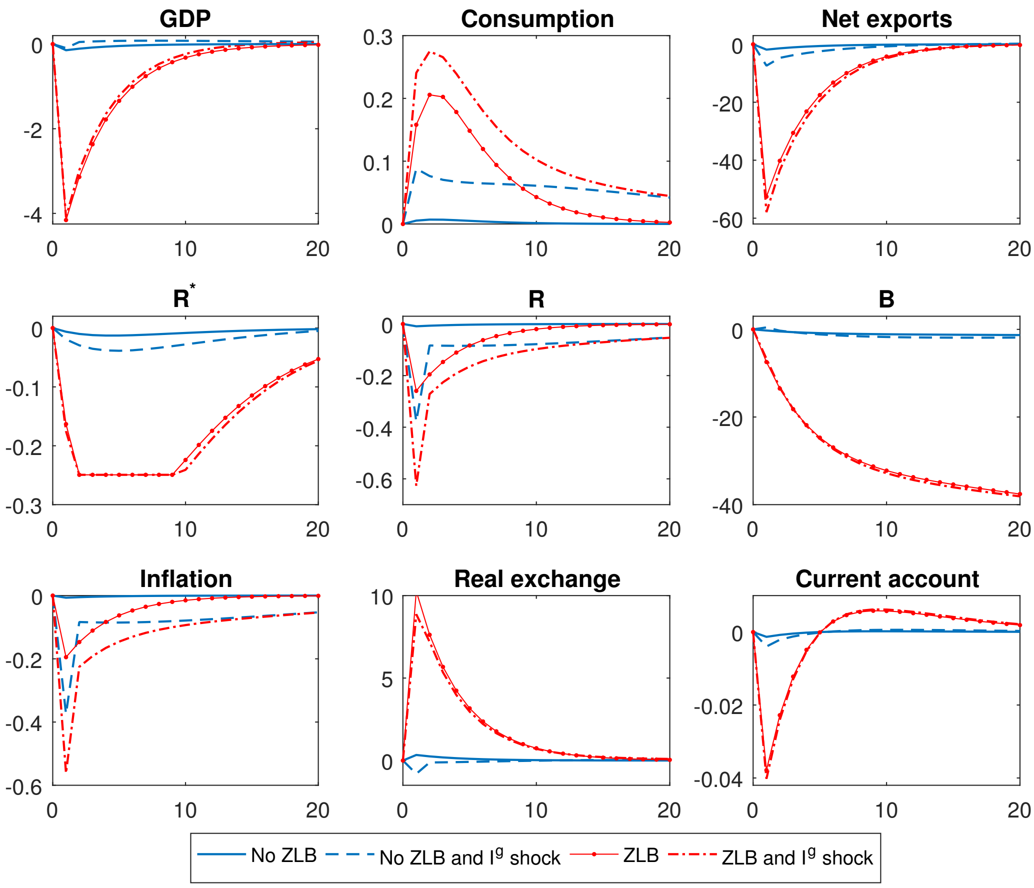

Figure 2: IRFs of the main variables following a positive government investment shock, contemporaneously with a negative exports shock under ZLB and normal times. The length of the ZLB is eight periods. Values are expressed in percentage deviations from steady state, except for current account which is in levels. Consumption accounts for household consumption only.

Turning to fiscal stimulus, under normal times (dashed line), an increment in government investment mitigates the negative effect of the exports demand shock on aggregate demand. Through the SOE production channel, an increment in government investment acts as a positive productive shock and increases the SOE intermediate goods production and, hence, the final goods production. The SOE production channel also produces a spill-over effect on the POE production, which increases the final goods production further. Intuitively, fiscal stimulus increases the expected wealth for households. Households, therefore, increase consumption, which encourages POEs to increase their production. Fiscal stimulus has a dis-inflationary effect and dampens inflation further.[10]

Under the global ZLB (dashed-dotted line), the effects of fiscal stimulus are enhanced, especially for consumption, inflation and domestic monetary policy rate. We see that, following the increment of government investment, household consumption increases significantly during the period that the global ZLB is binding. In the following section, we show that the present-value multiplier is 1.6, which confirms the finding here that there is no crowding out associated with fiscal stimulus. In a close-economy model setup, when the ZLB is binding, government investment tends to increase the expected inflation so that the economy can exist the liquidity trap and the policy rate becomes effective again. In our case, however, it is the foreign monetary policy rate is binding at ZLB, whereas the domestic monetary policy is not. Moreover, fiscal stimulus acts as a positive productivity shock and dampens the expected inflation. At the same time, the shock decreases the domestic monetary policy rate. The results here reproduce the business cycle fluctuations observed from the Chinese data.

4.2 Implementation delays

One of the key issues with government investment is the implementation delays. As pointed out by Leeper et al. (2010), implementation delays can produce small even negative growth effects in the short run. In this section, we investigate the effects of implementation delays in a global ZLB environment. Instead of an increment in government investment contemporaneously with an exports demand shock, we modify the model such that it captures the implementation delays for building public capital. Specifically, following Uhlig (2010) and Erceg and Linde (2014) we modify the government investment shock process (27) evolving

[10]This is elaborated in the following paragraph.

an AR(2) process:

$$I_t^g - I_{t-1}^g = \rho_{i,1}\left(I_{t-1}^g - I_{t-2}^g\right) - \rho_{i,2}\left(I_{t-1}^g - I^g\right) + \xi_{i,t} \tag{40}$$

where the parameters $\rho_{i,1}, \rho_{i,2} \in (0,1)$ are related to the timing of full implementation of government investment. Depending on the values of the parameters, full implementation is archieved after a number of periods. Notice that Equation 40 is reduced to an AR(1) process when $\rho_{i,1} = 0$, the same as in the original setup.

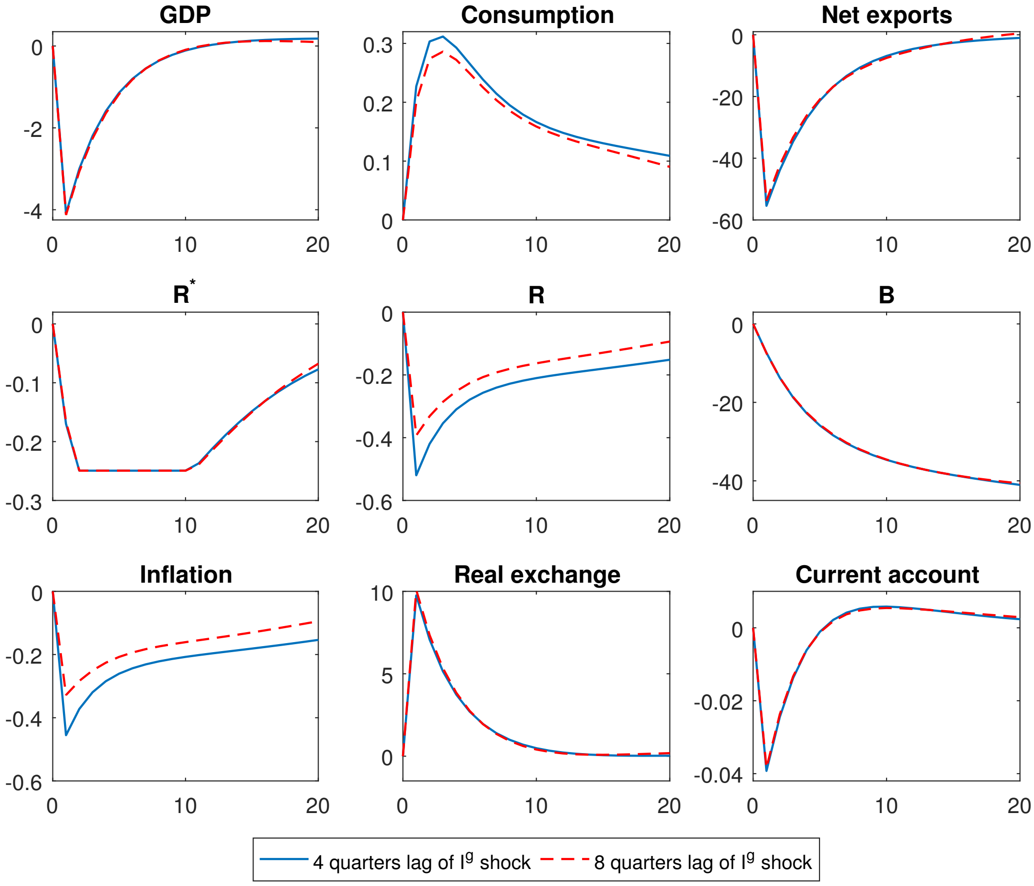

Figure 3: IRFs of the main variables following a positive government investment shock with implementation delays in a global ZLB environment. Values are expressed in percentage deviations from steady state, except for current account which is in levels. Consumption accounts for households consumption only.

Figure 3 reports the dynamics of the main variables in response to an increment of government investment shock with implementation delays in a global ZLB environment. We consider two cases: (i) when full implementation of fiscal stimulus is achieved 4 quarters after the shock (solid lines), with the parameter values of $\rho_{i,1} = 0.5$ and $\rho_{i,2} = 0.025$; and, (ii) when full implementation of fiscal stimulus requires 8 quarters (dashed lines), with the parameter values of $\rho_{i,1} = 0.9$ and $\rho_{i,2} = 0.025$. These parameter values are chosen such that the increment of government investment in the first period is 1%, which is the same as in our previous analysis.

Implementation delays do not have a significant impact on the dynamics of output.[11] It, however, produces favourable outcomes for household consumption and inflation. That is, with implementation delays, fiscal stimulus has a stronger positive impact on household consumption and, at the same time, it attenuates the dis-inflationary effect of the negative exports demand shock. Compared to the scenario where there is no implementation delays (see the IRFs under global ZLB (dashed-dotted) in Figure 2), household consumption increases slightly more with 4-quarter implementation delays. This exacerbation effect of implementation delays on household consumption becomes more visible when fiscal stimulus is only fully implemented with 8-quarter lag.

Implementation delays produce a price stabilization effect: inflation decreases much less when fiscal stimulus is implemented with lags. This effect becomes more significant when the delays are prolonged. As argued by Bouakez et al. (2016), under normal times or with short period implementation delays, the dis-inflationary effect associated with government investment shock is much stronger. With a longer period of implementation delays, since it takes much longer time to build public capital, the positive productivity effect associated with fiscal stimulus gradually attenuates inflation. A subsequent effect of this price stabilization is that it allows monetary authority to adjust its policy rate moderately, as opposed to the sharp decrease required when there are no implementation delays.

4.3 Government investment multipliers

In this section, we quantify the multiplier effect of fiscal stimulus using two measures commonly used in the literature: present-value multipliers and impact multipliers (for instance, Mountford and Uhlig, 2009; Leeper, Walker, and Yang, 2010).

[11] This finding is contrast to Leeper et al. (2010). Notice that the results from Leeper et al. (2010) are under normal times.

4.3.1 Present-value multipliers

The first measure used to quantify the multiplier effect of fiscal stimulus is the present value of government investment multipliers over k periods:

$$M_t^{pv}(k) = \frac{\sum_{i=0}^{k}(\prod_{j=0}^{i} R_{t+j}^{-1})\Delta GDP_{t+i}}{\sum_{i=0}^{k}(\prod_{j=0}^{i} R_{t+j}^{-1})\Delta I_{t+i}^{g}}, \tag{41}$$

where ΔGDP_t and ΔI_t^g are level changes in GDP and government investment with respect to their steady states in period t.

In the absence of any other shocks, the present-value multiplier of the fiscal stimulus, $M_t^{pv}(k)$, resulting from an increment of 1 percent in government investment, is approximately 1.66 (calculated based on 40 periods, so as $k = 40$). This is along the lines with the multiplier estimates from the empirical literature. For instance, Ilzetzki, Mendoza, and Végh (2013) report the government investment multiplier estimates for developed and developing countries are 1.5 and 1.6, respectively. On the theoretical literature front, Leeper et al. (2010) report the present-value multipliers which are slightly greater than 1, whereby Bouakez et al. (2016) find the multipliers are close to 1.

The productivity of public capital plays a critical role in determining the multiplier effects of government investment. In our model, public capital is the only capital input in the SOE production and its share towards the final goods production is 0.27.[12] This value is close to the estimates (0.24) based on log-linear production functions from Aschauer (1989). In Leeper et al. (2010), public capital enters into the production function directly as an additional capital input to private capital, with a share in the production of 0.1.[13] Bouakez et al. (2016) calibrate the productivity of public capital to 0.8. Our findings here confirm Leeper et al. (2010)'s argument that the productivity of public capital is a crucial parameter to determine the effects of government investment. Intuitively, more productive public capital (larger share of public capital in the production function) amplifies the impact of government investment.

[12] The total share of public capital in the production of final goods is calculated by multiplying its share in the SOE production function and the share of SOE-produced intermediate goods in the final goods production function. That is, $[(1-\alpha_s) = 0.6649]\left[\left(1-\alpha_r^i-\alpha_r^p\right) = 0.4065\right] = 0.2703$.

[13] The authors also consider an alternative value of 0.05.

4.3.2 Impact multipliers

The second measure is the impact multiplier calculated as the ratio of changes in GDP in period k and the initial changes in government investment (or maximum size of the shock when there are implementation delays):

$$M_{t+k} = \frac{\Delta GDP_{t+k}}{\Delta I_t^g}, \tag{42}$$

where ΔGDP_{t+k} is level changes in GDP with respect to its steady state in period $t+k$, and ΔI_t^g is the initial level changes of government investment, at time t.

We define the following impact multipliers under the global ZLB: M_{t+k}^{zlb} are the dynamic multipliers when government investment is implemented without delays, whereas $M_{t+k}^{zlb,4}$ and $M_{t+k}^{zlb,8}$ are the dynamic multipliers when government investment is fully implemented after 4 quarters and 8 quarters, respectively. Therefore, a positive difference between $M_{t+k}^{zlb,4}$ and M_{t+k}^{zlb} implies that fiscal stimulus with 4-quarter lag is more effective than that without delays. The opposite is true if the difference is negative. The same applies to impact multipliers with 8-quarter lag, $M_{t+k}^{zlb,8}$.

Figure 4 plots the differences between impact multipliers associated with delays and that without delays. The results show that, with both 4- and 8-quarter delays, implementation delays enhance the multiplier effects of fiscal stimulus. We see that, with a moderate period of implementation delays (4 quarters), this amplification effect tends to be more persistent, whereas with 8 quarters delays, the amplification effect starts to diminish 20 quarters after the government investment shock occurs. This is consistent with the results in Leeper et al. (2010), where the multiplier effect of government investment decreases as the period of implementation delays increases.[14]

It is worth noting that the differences between impact multipliers associated with delays and that without delays are negative in the first two periods after the shock occurs. It shows that it at least takes a few periods for building public capital and for implementation delays to start producing its amplification effect. Intuitively, fiscal stimulus is purely implemented through the SOE production channel, whereas the POEs do not benefit from the fiscal stimulus either directly or immediately. As mentioned previously, POEs benefit from fiscal

[14]See tables 3 and 4 in Leeper et al. (2010), the present-value multipliers associated with higher share of government investment in the production function ($\alpha = 0.1$).

stimulus through the spill-over effect associated with the SOE production channel. It takes time for the spill-over effect take place. Fiscal stimulus generates a positive wealth effect and the expected household consumption increases. POEs, therefore, increase their production even though they do not receive government investment directly.

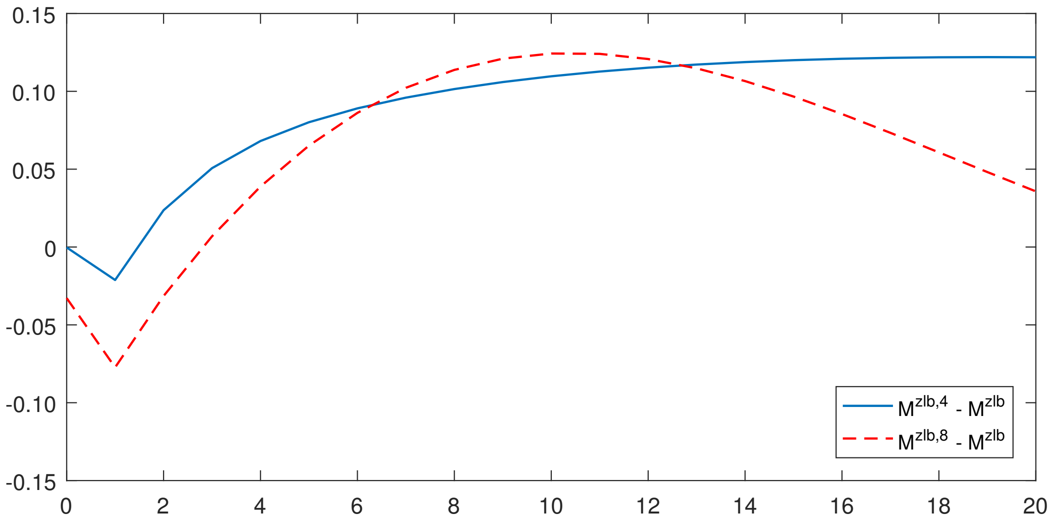

Figure 4: Government investment impact multipliers in a global ZLB: no delays vs with delays. Solid line: $M^{zlb,4}_{t+k} - M^{zlb}_{t+k}$; dashed line: $M^{zlb,8}_{t+k} - M^{zlb}_{t+k}$.

4.4 Welfare implications

To complement our analysis, we report the welfare implications of fiscal stimulus, under normal times, under global ZLB, and with implementation delays. Welfare is defined as the stream of discounted utility of households in Equation 1.

Figure 5 plots the welfare dynamics under all scenarios considered in the study and shows that, in general, fiscal stimulus improves social welfare. Recall that household consumption increases following the implementation of fiscal stimulus. The dis-inflationary effect of fiscal stimulus increase household consumption further. Under the global ZLB, welfare increases significantly as a result of much higher household consumption associated with the enhanced multiplier effect. This finding is consistent with those from the literature (e.g., Christiano et al., 2011; Nakata, 2016), where government investment can improve social welfare substantially at the ZLB. Implementation delays improves social welfare even further as it enhances the multiplier effects of fiscal stimulus, as shown in the previous section.

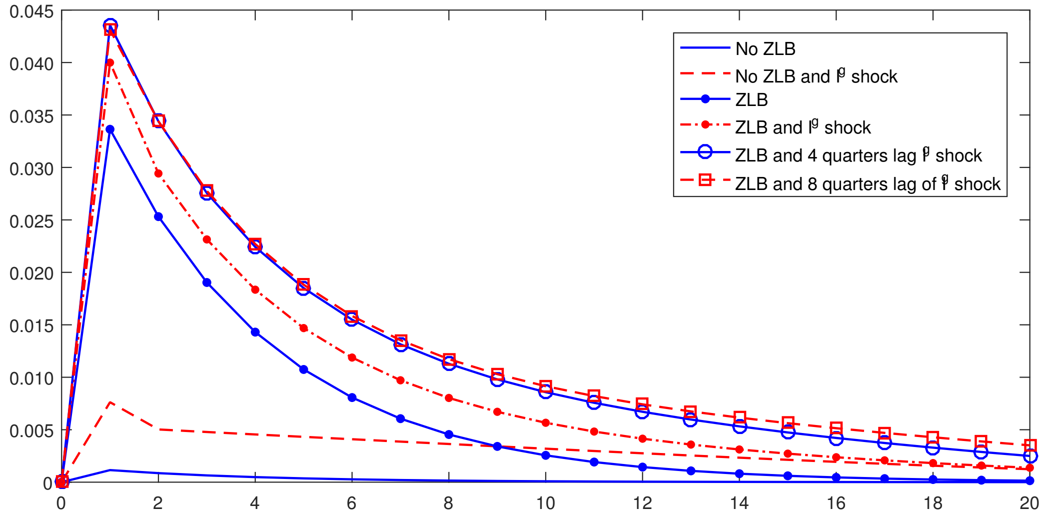

Figure 5: Welfare dynamics expressed in percentage deviations from steady state. The solid line displays the welfare following a negative exports demand shock with size of 1% under normal times (*no ZLB*); the dashed line displays the welfare following a negative exports demand shock and a contemporaneous government investment increment; the dotted-solid line displays the welfare following a negative exports shock of size 25% (global ZLB); the dotted-dashed line displays the welfare following a government investment shock under the global ZLB; the circled solid line represents the welfare following a government investment shock with 4-quarter lag under the global ZLB and the squared-solid line represents the same with 8-quarter lag.

5 Conclusion

This paper studies the effects of government investment when nominal interest rate is constrained at ZLB from an emerging market perspective. We develop a model which captures the significant decline in China's net exports and remarkable quantity of resources that the Chinese government invested into the economy through state-owned enterprises in the aftermath of the 2007-2008 global financial crisis. We show that fiscal stimulus has played an important role in dampening the economic downturn resulting from the significant decline in exports demand. The state-owned entrepreneur production channel amplifies the multiplier effects of fiscal stimulus and produces a present-value multiplier of 1.6. In a global ZLB environment, fiscal stimulus has a dis-inflationary effect and dampens the expected inflation. Fiscal stimulus improves welfare significantly as a result of much higher household consumption associated with the enhanced multiplier effect. Implementation delays enhance the multiplier effect and the price stabilization effect of fiscal stimulus. It also improves social welfare significantly.

As a starting point, the focus of this paper is not on how fiscal deficits are ultimately financed. We include government bonds and different types of taxes in the model to simply improve the model's capability to match the Chinese data. We leave the impact of how fiscal deficits are ultimately financed on fiscal stimulus as feature research.

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A Appendix: Model equations

$$B_t + (1+\tau_c)\,C_t + I_t^p = \frac{R_{t-1}B_{t-1}}{\pi_t} + r_{t-1}^{k,p}K_{t-1}^p + (1-\tau_l)\,W_tL_t + \Psi_t^r + Z_t, \tag{A.1}$$

$$K_t^p = (1-\delta)\,K_{t-1}^p + (1-\Omega_t^p)\,I_t^p, \tag{A.2}$$

$$\lambda_t = \beta\lambda_{t+1}R_t/\pi_{t+1}, \tag{A.3}$$

$$\left(C_t - hC_{t-1}\right)^{-1} - \beta h\left(C_{t+1} - hC_t\right)^{-1} = (1+\tau_c)\,\lambda_t, \tag{A.4}$$

$$\lambda_t = \lambda_t^k\left[1 - \Omega_t^p - \Omega_t^{p'}I_t^p\right] - \beta\lambda_{t+1}^k\Omega_{t+1}^{p'}I_{t+1}^p, \tag{A.5}$$

$$\lambda_t^k = \beta\left[\lambda_{t+1}r_t^{k,p} + \lambda_{t+1}^k\left(1-\delta_p\right)\right], \tag{A.6}$$

$$(1-\tau_l)\,\lambda_tW_t = \gamma\,(1-L_t)^{-1}, \tag{A.7}$$

$$Y_t^p = (L_t^p)^{\alpha_p}\left(K_{t-1}^p\right)^{1-\alpha_p}, \tag{A.8}$$

$$\Psi_t^p = Q_t^pY_t^p - W_tL_t^p - r_{t-1}^{k,p}K_{t-1}^p, \tag{A.9}$$

$$K_t^p = \left(1-\alpha_p\right)Q_{t+1}^pY_{t+1}^p/r_t^{k,p}, \tag{A.10}$$

$$L_t^p = \alpha_pQ_t^pY_t^p/W_t, \tag{A.11}$$

$$Y_t^s = (L_t^g)^{\alpha_s}\left(K_{t-1}^g\right)^{1-\alpha_s}, \tag{A.12}$$

$$\Psi_t^s = Q_t^sY_t^s - W_tL_t^g - r_{t-1}^{k,g}K_{t-1}^g, \tag{A.13}$$

$$K_t^g = (1-\alpha_s)\,Q_{t+1}^sY_{t+1}^s/r_t^{k,g}, \tag{A.14}$$

$$L_t^g = \alpha_sQ_t^sY_t^s/W_t, \tag{A.15}$$

$$Y_t = \left(X_t^i\right)^{\alpha_r^i} \left(Y_t^p\right)^{\alpha_r^p} \left(Y_t^s\right)^{1-\alpha_r^i-\alpha_r^p}, \tag{A.16}$$

$$\alpha_r^i \lambda_t^r Y_t / X_t^i - S_t = 0, \tag{A.17}$$

$$\alpha_r^p \lambda_t^r Y_t / Y_t^p - Q_t^p = 0, \tag{A.18}$$

$$\left(1 - \alpha_r^i - \alpha_r^p\right) \lambda_t^r Y_t / Y_t^s - Q_t^s = 0, \tag{A.19}$$

$$\epsilon \lambda_t^r = (\epsilon - 1) + (\Omega_r / Y_t) \left\{ \left[(\pi_t/\pi) - 1\right] (C_t \pi_t / \pi) - \left(\Lambda_{t+1}/\Lambda_t\right) \left[\left(\pi_{t+1}/\pi\right) - 1\right] \left(Y_{t+1}\pi_{t+1}/\pi\right) \right\}, \tag{A.20}$$

$$S_t B_t^* + G_t + I_t^g + \frac{R_{t-1} B_{t-1}}{\pi_t} + Z_t = B_t + S_t (1 - \tau_b) R_{t-1}^* B_{t-1}^* + \tau_c C_t + \tau_l W_t L_t + r_{t-1}^{k,s} K_{t-1}^g, \tag{A.21}$$

$$K_t^g = (1 - \delta) K_{t-1}^g + (1 - \Omega_t^g) I_t^g, \tag{A.22}$$

$$G_t = \omega_g GDP_t, \tag{A.23}$$

$$Z_t = \omega_z GDP_t, \tag{A.24}$$

$$\log\left(I_t^g\right) = \rho_i \log\left(I^g\right) + (1 - \rho_i) \log\left(I_{t-1}^g\right) + \xi_{i,t}, \tag{A.25}$$

$$R_t = R \left(GDP_t / GDP\right)^{\theta_{gdp}} \left(\pi_t / \pi\right)^{\theta_\pi}, \tag{A.26}$$

$$GDP_t \equiv C_t + G_t + I_t^p + I_t^g + X_t^e - S_t X_t^i, \tag{A.27}$$

$$L_t = L_t^g + L_t^p, \tag{A.28}$$

$$Y_t = C_t + G_t + I_t^p + I_t^g + X_t^e + \Omega_t, \tag{A.29}$$

$$\Omega_t = \Omega_t^g + \Omega_t^p + \Omega_t^r, \tag{A.30}$$

$$X_t^e = (S_t)^{\epsilon_q} \chi_t, \tag{A.31}$$

$$\log(\chi_t) = \rho_\chi \log(\chi) + \left(1 - \rho_\chi\right) \log(\chi_{t-1}) + \xi_{\chi,t}, \tag{A.32}$$

$$S_t B_t^* = X_t^e - S_t X_t^i + S_t (1 - \tau_b) R_{t-1}^* B_{t-1}^*, \tag{A.33}$$

$$CA_t = S_t \left(B_t^* - B_{t-1}^*\right), \tag{A.34}$$

$$\log\left(R_t^*\right) = (1 - \rho_r) \log\left(R^*\right) + \rho_r \log\left(R_{t-1}^*\right) + \xi_{r,t}. \tag{A.35}$$

$$\Omega_t^p \equiv (\Omega_p/2)\left[\left(I_t^p/I_{t-1}^p\right)-1\right]^2, \tag{A.36}$$

$$\Omega_t^g \equiv (\Omega_g/2)\left[\left(I_t^g/I_{t-1}^g\right)-1\right]^2, \tag{A.37}$$

$$\Omega_t^r \equiv (\Omega_r/2)\left[\left(P_{j,t}/\pi P_{j,t-1}\right)-1\right]^2. \tag{A.38}$$

B Appendix: Parameter values and target ratios

B.1 α_p and α_s

To obtain α_p and α_s, from Equation 12, solve Q^pY^p:

$$Q^pY^p = \frac{r^{k,p}K^p}{(1-\alpha_p)}, \tag{B.1}$$

and assuming that $L^p = L^s$, we can equalize the half of the ratio of total wage bill to GDP and Equation 13, so as:

$$\frac{1}{2}\frac{WL}{GDP} = \frac{WL^p}{GDP} = \alpha_p \frac{Q^pY^p}{GDP}, \tag{B.2}$$

substituting Equation B.1 into it and solving for α_p yield:

$$\begin{aligned} \frac{1}{2}\frac{WL}{GDP}(1-\alpha_p) &= \alpha_p \frac{r^{k,p}K^p}{GDP} \leftrightarrow \\ \frac{1}{2}\frac{WL}{GDP} &= \alpha_p\left(\frac{1}{2}\frac{WL}{GDP} + \frac{r^{k,p}K^p}{GDP}\right) \leftrightarrow \\ \alpha_p &= \frac{1}{2}\frac{WL/GDP}{\left(\frac{1}{2}\frac{WL}{GDP} + \frac{r^{k,p}K^p}{GDP}\right)}. \end{aligned} \tag{B.3}$$

Analogously for the SOEs, we obtain:

$$\alpha_s = \frac{1}{2}\frac{WL/GDP}{\left(\frac{1}{2}\frac{WL}{GDP} + \frac{r^{k,s}K^s}{GDP}\right)}. \tag{B.4}$$

B.2 α_r^i

Substituting the market clearing condition (Equation 35) into the GDP definition in Equation 29:

$$\begin{aligned} Y &= C + G + I^p + I^g + X^e, \\ GDP &= C + G + I^p + I^g + X^e - X^i, \longrightarrow \\ GDP &= Y - X^i, \end{aligned} \tag{B.5}$$

and using imports demand from Equation 22:

$$X^i = \alpha_r^i \lambda^r Y, \tag{B.6}$$

we can express $GDP = (1 - \alpha_r^i \lambda^r)\, Y$;

The target ratio of imports over GDP is then:

$$X^i/GDP = 0.27 = \alpha_r^i \lambda^r / \left(1 - \alpha_r^i \lambda^r\right), \tag{B.7}$$

and the value of λ^r is obtained Equation 38, thereafter, we solve for α_r^i.

B.3 τ_c and τ_l

To obtain the taxes on consumption and labor, we use the budget constraints of households and government, Equation 2 and Equation 25, and divide them by GDP.

$$\frac{(1+\tau_c)\,C}{GDP} + \frac{I^p}{GDP} = \frac{(R-1)\,B}{GDP} + \frac{r^{k,p}K^p}{GDP} + \frac{(1-\tau_l)\,WL}{GDP} + \underbrace{\Psi^p}_{=0} + \underbrace{\frac{\Psi^r}{GDP}}_{(i)} + \frac{Z}{GDP}, \tag{B.8}$$

$$\frac{G}{GDP} + \frac{I^g}{GDP} + \frac{(R-1)\,B}{GDP} + \frac{Z}{GDP} = \frac{[(1-\tau_b)\,R^* - 1]\,B^*}{GDP} + \frac{\tau_c C}{GDP} + \tau_l \underbrace{\frac{WL}{GDP}}_{(ii)} + \frac{r^{k,s}K^g}{GDP} + \underbrace{\Psi^s}_{=0}, \tag{B.9}$$

All the target ratio values are known and we just need to obtain: (i) the ratio of retailers to GDP, Ψ^r/GDP; and (ii) the total wage bill to GDP, WL/GDP.

For (i) we substitute the retailers FOCs into the definition of retailers profits, so as:

$$\Psi^r = Y - \underbrace{Q^p Y^p}_{(a)} - \underbrace{Q^s Y^s}_{(b)} - \underbrace{X^i}_{(c)}, \tag{B.10}$$

$$(a) : Q^p Y^p = \alpha_r^p \lambda^r Y, \tag{B.11}$$

$$(b) : Q^s Y^s = \left(1 - \alpha_r^i - \alpha_r^p\right) \lambda^r Y, \tag{B.12}$$

$$(c) : X^i = \alpha_r^i \lambda^r Y, \tag{B.13}$$

thereafter, we divide it by GDP and obtain:

$$\Psi^r / GDP = (1 - \lambda^r) / \left(1 - \alpha_r^i \lambda^r\right). \tag{B.14}$$

And for (ii), from the POEs and SOEs profits equations (11) and (16), we solve each wage bill paid, WL^p and WL^s, and sum them up:

$$\Psi^p = Q^p Y^p - WL^p - r^{k,p} K^p = 0 \longleftrightarrow \tag{B.15}$$
$$WL^p = Q^p Y^p - r^{k,p} K^p.$$

$$\Psi^s = Q^s Y^s - WL^s - r^{k,s} K^g = 0 \longleftrightarrow \tag{B.16}$$
$$WL^s = Q^s Y^s - r^{k,s} K^g.$$

$$W\left(L^p + L^s\right) = \underbrace{Q^p Y^p}_{(d)} + \underbrace{Q^s Y^s}_{(e)} - r^{k,p} K^p - r^{k,s} K^g. \tag{B.17}$$

We substitute (e) and (f), from the retailers FOCs (23) and (24):

$$(d) : Q^p Y^p = \alpha_r^p \lambda^r Y, \tag{B.18}$$

$$(e) : Q^s Y^s = \left(1 - \alpha_r^i - \alpha_r^p\right) \lambda^r Y, \tag{B.19}$$

$$W\left(L^p+L^s\right)=WL=\alpha_r^p\lambda^r Y+\left(1-\alpha_r^i-\alpha_r^p\right)\lambda^r Y-r^{k,p}K^p-r^{k,s}K^g\rightarrow$$
$$WL=\left(1-\alpha_r^i\right)\lambda^r Y-R^k K^p-R^k K^g, \tag{B.20}$$

divide by GDP and substitute the target ratios:

$$WL/GDP=\left(1-\alpha_r^i\right)\lambda^r/\left(1-\alpha_r^i\lambda^r\right)-r^k\left(K^p+K^g\right)/GDP, \tag{B.21}$$

where $K^j/GDP=I^j/\delta GDP$, $j\in\{p,s\}$.

Then all the ratios with respect to GDP can be used and we can solve for τ_c and τ_l with the two equations above.

B.4 τ_b

We divide the trade balance (Equation 32) by GDP, use the target ratio and foreign rate values and solve for τ_b:

$$B^*=X^e-X^i+\left(1-\tau_b\right)R^*B^*\longrightarrow$$
$$\frac{B^*}{GDP}=\frac{X^e-X^i}{GDP}+\frac{R^*B^*}{GDP}-\tau_b\frac{R^*B^*}{GDP}\longrightarrow$$
$$\tau_b=\frac{1}{R^*B^*/GDP}\left(\frac{X^e-X^i}{GDP}+\frac{R^*B^*}{GDP}-\frac{B^*}{GDP}\right). \tag{B.22}$$