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Central Bank Independence and Inflation: Schumpeterian Theory and Evidence*

Qichun He and Heng-fu Zou†

We first use a monetary Schumpeterian model to investigate how central bank independence (CBI) affects inflation. It is found that we can predict a mixed, non-monotonic relationship between CBI and inflation. Under inelastic labor supply, when the seigniorage is mainly used to finance entrepreneurs, a condition that is more likely in developed countries, CBI has a positive effect on inflation; in contrast, when the seigniorage is mainly used to finance non-productive government spending, a situation more commonly found in developing countries, CBI has a negative effect or no effect on inflation. As an empirical test, we build panel data for 68 countries during 1998–2010 and find that the effect of CBI on inflation is positive and significant in developed countries, and it is insignificant (at the 5% level) in developing countries in both system generalized method of moments (GMM) and instrumental variable (IV) estimations. Our results remain robust to the consideration of financial crises, financial development, and other factors affecting inflation. Our empirical findings provide support for our theory.

Key Words: Inflation; Central Bank Independence; Monetary Schumpeterian Model; Dynamic Panel Data.
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1. INTRODUCTION

Scholars debate on whether central bank independence (CBI) helps reduce inflation (e.g., Alesina and Summers, 1993; Cukierman and Lippi,

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† He: Corresponding Author. Central University of Finance and Economics, No. 39 South College Road, Haidian District, Beijing, China. 100081. Email: qichunhe@gmail.com, heqichun@cufe.edu.cn; Zou: Central University of Finance and Economics, No. 39 South College Road, Haidian District, Beijing, China. Email: hzoucema@gmail.com.

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1999; De Haan and Kooi, 2000; Cukierman et al., 2002; Neyapti, 2003; Jácome and Vázquez, 2005; Crowe and Meade, 2008; Klomp and De Haan, 2010; Dincer and Eichengreen, 2014). In this paper we contribute by using a monetary Schumpeterian model to investigate how CBI impacts inflation.[1] Doing so would help us to further understand the role of CBI in the making of monetary policy. Additionally, we build cross-country panel data during 1998–2010 to test our model.

CBI usually refers to that the central bank should be independent from fiscal authority, which is to avoid the time-inconsistency problem. One additional reason for CBI is to prevent the monetization of public debt, which we highlight in this paper. Specifically, we introduce money into a Schumpeterian model through the CIA (cash-in-advance) constraint on consumption. We assume that the seigniorage revenue is allocated between households and entrepreneurs (other cases will also be investigated). A higher degree of CBI would increase the share of the seigniorage revenue allocated to entrepreneurs. Our model illustrates that we cannot predict a monotone relationship between CBI and inflation. Under inelastic labor supply, in countries where the step-size of innovation is small, CBI has a positive effect on inflation; in contrast, in countries where the step-size of innovation is large, CBI has a negative effect on inflation. Our results hold up when the taste for leisure is low under elastic labor supply.

The economic intuition for the inelastic labor supply case is as follows. A higher nominal interest rate would yield larger seigniorage revenue. When a larger share of the seigniorage revenue is used to subsidize R&D, it increases R&D labor—the *seigniorage effect* highlighted in He and Zou (2016). When the step-size of innovation is small, there is R&D overinvestment. In this case, the optimal interest rate would be smaller than ρ (the rate of time preference). When this happens, there would be negative seigniorage revenue, which means the entrepreneurs are taxed according to the low nominal interest rate. A resultant decrease in R&D labor would be welfare-improving when there is R&D overinvestment. When the step-size of innovation is large, there is R&D underinvestment. In this case, the optimal interest would be above ρ, yielding positive seigniorage revenue. The positive seigniorage revenue allocated to entrepreneurs would increase R&D labor, which is welfare-improving when there is R&D underinvestment.

An increase in the nominal interest rate has two opposing effects on welfare. On the one hand, it increases R&D labor and thereby the growth rate (i.e., future consumption), thereby increasing welfare. On the other hand, it reduces manufacturing labor (i.e., initial consumption), decreasing

[1]For studies using the R&D-driven growth-theoretic framework, see Marquis and Reffett (1994); Chu and Lai (2013); Chu and Cozzi (2014); Chu et al. (2014); Chu et al. (2015); Huang et al. (2015); Chu et al. (2017); He, 2018 (a,b); Chu, Ning, and Zhu (2019); Chu et al. (2019); He et al. (2023).

welfare. We can view the seigniorage effect as the marginal benefit of an increase in the nominal interest rate. The marginal cost is proportional to the step-size of innovation. For a fixed marginal cost, the marginal benefit must remain unchanged. An increase in the degree of CBI increases the marginal benefit of an increase in the nominal interest rate. When the step-size of innovation is small, the optimal nominal interest rate has to increase: an increase in the nominal interest rate when it is below ρ would increase the seigniorage, thereby decreasing the seigniorage effect. When the step-size of innovation is high, an increase in the degree of CBI would cause the optimal nominal interest rate to decrease; a decrease in the nominal interest rate when it is above ρ would decrease the seigniorage and, therefore, the seigniorage effect.[2] Calibration confirms our theoretical predictions.

As an empirical test, we build panel data for 68 countries during 1998–2010 (a balanced panel with 884 observations). Following the existing literature (e.g., Dincer & Eichengreen, 2014), we use the logarithm of (1+inflation) as the dependent variable. We find that the effect of CBI on inflation is positive and significant at the 5% level in advanced countries, and it is insignificant at the 5% level in developing countries in system GMM (generalized method of moments) regressions and IV (instrumental variable) estimation that uses legal origins as instruments. Our results remain robust after controlling for many important variables. Our empirical findings provide support for our theory.

People may question why it is necessary to explore the discussion of CBI and inflation within an endogenous growth framework. The reason is twofold. First, although the DSGE (dynamic stochastic general equilibrium) framework is one of the workhorses in macroeconomics, it often neglects the endogenous growth part. One needs long-run growth to study the long-run growth effect of monetary policy. That is why the Schumpeterian growth framework that endogenizes long-run growth is important. The disconnect between the DSGE framework that mainly focuses on the short-run issues and the Schumpeterian framework that highlights long-run growth should not be the reason to study monetary policies solely in the DSGE framework. Second, growth consists of an important if not dominant part of the welfare. Without long-run growth, the study of optimal monetary policy on growth and welfare is not complete. For example, He et al (2023) have discussed that the effect of monetary policy on growth/welfare and the relationship between the real and nominal interest rates are quite different in endogenous growth models than in the DSGE models. In this sense, we need more studies on optimal monetary policy in endogenous growth framework including the Schumpeterian one our study uses (ex-

[2] We then consider elastic labor supply. When the taste for leisure is high, CBI is more likely to have a positive effect on inflation; when it is low, CBI tends to decrease inflation.

isting studies on the inflation-growth nexus in the R&D-based framework include, for example, Hu, Yang and Zheng, 2021; Zheng, Huang, and Yang, 2021; Huang, Wu, Yang, and Zheng, 2023). Future studies may improve on our current one by further considering capital accumulation (Iwaisako and Futagami, 2013).

People may also suspect that the fundamental argument for CBI is low seigniorage, rather than how it is allocated. But our study shows that the allocation of seigniorage plays a crucial role in determining the optimal monetary policy and thereby the level of seigniorage. Moreover, our study illustrates that whether CBI brings low seigniorage depends on structural parameters (i.e., there is not necessarily a negative, monotone relationship between CBI and seigniorage). It is likely that CBI brings high seigniorage in developed countries and low seigniorage in developing countries, which is supported by empirical evidence. In sum, our study has profound implications for the role of CBI in the making of optimal monetary policy in a Schumpeterian framework.

Our study contributes to the literature on CBI and its effect on inflation, government deficits, growth, and welfare (see e.g., De Haan and Zelhorst, 1990; Grilli et al., 1991; Cukierman et al., 1992; Fischer, 1995; Hochreiter et al., 1996; Sikken and De Haan, 1998, and references cited above). Our study builds on He and Zou (2016) who highlight the allocation of seigniorage in Schumpeterian models. However, He and Zou (2016) focus on growth, leaving the optimal monetary policy unsolved. Our study focus on optimal monetary policy and how the monetary policy may be influenced by the degree of central bank independence, which also has profound policy implications.

The rest of the paper proceeds as follows. After we discuss the model assumptions, Section 2 presents the model. Section 3 displays the empirical evidence. Section 4 concludes.

1.1. CBI and the Allocation of Seigniorage Revenue

Our model features the assumption that the seigniorage revenue is allocated between entrepreneurs/households and the government, which has real world relevance, as elaborated upon below.

First, the revenue from steady money growth (i.e., the seigniorage revenue) is large in developed countries, and it is even larger in developing countries (see De Haan and Zelhorst, 1990; Obtsfeld and Rogoff, 1996, p. 527; Kime, 1998; Miles and Scott, 2005, p. 278). Seigniorage revenue also changes with the tightness of monetary policy (see Kime, 1998). According to Kime, during the period 1987-1994, for high inflation countries such as Argentina, Brazil and Peru, seigniorage revenue from currency issue is 2.2%, 2.3% and 3.7% of GDP, respectively. For countries with moderate inflation such as Colombia, Mexico, Turkey, seigniorage revenue is 1.3%, 1.0% and 1.2% of GDP, respectively.

Second, the seigniorage revenue may be used to finance government spending in many countries, particularly in developing and transitional countries. Blinder (1982) was among the first to discuss the possibility that government debt may be monetized (see also Sargent, 1987, Ch. 5). In developing countries where the central bank generally comes under direct control of the ministry of finance, seigniorage revenue is argued to be used by the government to finance its spending (see e.g., De Haan and Zelhorst, 1990; Hochreiter et al., 1996). For instance, Hochreiter et al. (1996) examine the relations between central banks and other macro sectors in the Czech Republic, Hungary and Romania, concerning the creation and distribution of seigniorage. They find that in the transitional countries, transfers of seigniorage from the central bank to the government may be a natural way to soften the financial constraint of the government.

Third, the literature on CBI reveals substantial variations in the degree of CBI across countries (see Grilli, Masciandaro, and Tabellini, 1991; Cukierman et al., 1992; Alesina and Summers, 1993; De Haan and Kooi, 2000; Dincer and Eichengreen, 2014). CBI usually means that the central bank should be independent from the fiscal authority or elected government. The reason is double-fold. First, the fiscal authority or elected government cannot force the central bank to adjust their monetary policy. With the commitment of the central bank to avoid the time inconsistency problem, low inflation rates are maintained. Second, the government cannot pressure the central bank to partly finance its expenditures; otherwise, the central bank will lose the ability to control inflation. Therefore, seigniorage revenue is less likely to be used to finance government spending with more independent central banks.

2. A MONETARY SCHUMPETERIAN MODEL

We use the Schumpeterian quality ladder model of Aghion and Howitt (1992). The essential elements of the Schumpeterian model are kept in Chu and Cozzi (2014), He and Zou (2016) and He et al. (2023). We improve on He and Zou (2016) by focusing on optimal monetary policy.

2.1. Households

There is a unit continuum of identical households whose population size is fixed at L at time t. Each representative household has a lifetime utility function

$$U = \int_0^\infty e^{-\rho t} \left[\ln\left(c_t\right) + \theta \ln\left(1 - l_t\right)\right] dt, \tag{1}$$

where c_t is per capita real consumption of final goods and l_t is per capita supply of labor at time t. $\rho > 0$ is the rate of time preference and $\theta \geq 0$ measures leisure preference (a large θ means a high taste for leisure). Each household maximizes its lifetime utility given in (1) subject to the following asset-accumulation equation

$$\dot{a}_t + \dot{m}_t = r_t a_t + w_t l_t - c_t - \pi_t m_t + (1-\beta)\,\tau_t, \tag{2}$$

where a_t is the real value of equity shares in monopolistic intermediate-goods firms owned by each person of households; r_t and w_t are the rate of real interest and the wage, respectively; m_t is the real money balance held by each member; and π_t is the inflation rate. Each individual receives a lump-sum transfer of $(1-\beta)$ share $(0 \leq \beta \leq 1)$ of the seigniorage revenue τ_t (or pay a lump-sum tax if $\tau_t < 0$). The CIA constraint is given by $c_t \leq m_t$.

Using Hamiltonian (see Appendix A), the optimality condition for consumption is

$$\frac{1}{c_t} = \mu_t\,(1 + i_t)\,, \tag{3}$$

where μ_t the Hamiltonian co-state variable on (2), $i_t = \pi_t + r_t$ is the nominal interest rate. Optimal labor supply is determined by

$$\frac{\theta}{1 - l_t} = w_t \mu_t. \tag{4}$$

Using (3), the optimal condition for labor supply can be rewritten as

$$w_t\,(1 - l_t) = \theta c_t\,(1 + i_t)\,. \tag{5}$$

The Euler equation is

$$-\frac{\dot{\mu}_t}{\mu_t} = r_t - \rho. \tag{6}$$

2.2. Firms

There is a competitive final goods sector and a monopolistic intermediate goods sector. The final goods firms use the differentiated intermediate goods as the sole input:

$$y_t = \exp\left(\int_0^1 \ln x_t\,(n)\,dn\right), \tag{7}$$

where $x_t\,(n)$ denotes intermediate goods $n \in [0, 1]$. The price of each intermediate good n is $p_t\,(n)$. Profit-maximization of the final goods firms yield the demand function for $x_t(n)$:

$$x_t(n) = y_t / p_t(n) \,. \tag{8}$$

There is a unit continuum of industries producing differentiated intermediate goods in the monopolistic intermediate goods sector. Each industry produces one intermediate good, with labor as the sole input:

$$x_t(n) = \gamma^{N_t(n)} L_{x,t}(n), \tag{9}$$

where $L_{x,t}(n)$ is the labor in industry n, $\gamma > 1$ is the step size of innovation, and $N_t(n)$ is the number of innovations that have occurred in industry n by time t.

(9) shows that new innovations come as the form of saving time: intermediate goods firms produce goods with less time. A new innovation reduces the marginal cost from $w_t/\gamma^{N_t(n)}$ to $w_t/\gamma^{N_t(n)-1}$. Bertrand price competition means the owner of the new innovation will charge a price equal to the marginal cost of the previous innovation, which is the business stealing effect that means the owner of the old innovation will be driven out of market. Therefore, we have the labor income from production as

$$w_t L_{x,t}(n) = \left(\frac{1}{\gamma}\right) p_t(n)\, x_t(n) = \left(\frac{1}{\gamma}\right) y_t. \tag{10}$$

The monopolistic profit is in the amount

$$\Pi_t(n) = \left(1 - \frac{1}{\gamma}\right) p_t(n)\, x_t(n) = \left(\frac{\gamma - 1}{\gamma}\right) y_t. \tag{11}$$

2.3. Government

The policy instrument (chosen by the central bank and the government) is the monetary growth rate $\dot{M}_t/M_t$ or the nominal interest rate. The justification is as follows. We have $m_t = M_t/(P_t L)$, where P_t is the price of final-goods and $\dot{P}_t/P_t = \pi_t$. Therefore, we have $\dot{m}_t/m_t = \dot{M}_t/M_t - \pi_t$. On the balanced growth path, c_t and m_t grow at the same rate g_t. Combining equations (3) and (6) yields $g_t = r_t - \rho$. The Fisher equation holds $i_t = r_t + \pi_t$. Taken together, we have $\dot{M}_t/M_t = i_t - \rho$, which shows that it is equivalent for the government to either the monetary growth rate $\dot{M}_t/M_t$ or the nominal interest rate as the policy instrument.

The seigniorage revenue R_t is

$$R_t = \frac{\dot{M}_t}{P_t} = \left(\frac{\dot{m}_t}{m_t} + \pi_t\right) \frac{m_t L}{y_t} y_t = (g_t + \pi_t)\, \phi_t y_t = (i_t - \rho)\, \phi_t y_t, \tag{12}$$

where we use the balanced growth path property, and $\phi_t = Lm_t/y_t$ is the endogenous money-output ratio.

We rewrite $R_t = \dot{M}_t/P_t = \left(\dot{m}_t + \pi_t m_t\right) L$. In existing literature, it is assumed that the government rebates the seigniorage as a lump-sum transfer to households, with per capita transfer as $\tau_t = R_t/L$. However, our study deviates from this assumption. The government collects the seigniorage revenue to finance lump-sum transfer to households, R&D subsidies S_t, and non-productive government expenditure G_t subject to the following balanced-budget condition:

$$R_t = (1-\beta)\,\tau_t L + S_t + G_t. \tag{13}$$

We are interested in the case where households and the entrepreneurs get $(1-\beta)$ and β share of the seigniorage revenue (i.e., $S_t = \beta R_t$). β is exogenously pinned down by the central bank laws, and it increases with the degree of CBI. In this case, we have $G_t = 0$. We will discuss other cases (e.g., $S_t = 0$ and $G_t > 0$; or $S_t > 0$ and $G_t > 0$).

2.4. R&D

Labor is also the sole input of R&D. In each industry, there is a unit continuum of R&D firms which hire workers to conduct R&D. We denote by $v_t\,(n)$ the value of the monopolistic firm in industry n. In a symmetric equilibrium, $v_t\,(n) = v_t$. There is free entry into R&D, which yields the zero-expected-profit condition of R&D firm $j \in [0,1]$ in each industry as

$$\lambda_t\,(j)\, v_t = w_t L_{r,t}(j), \tag{14}$$

where $L_{r,t}(j)$ is the amount of labor hired by R&D firm j, and $\lambda_t\,(j)$ is the firm-level innovation rate per unit time. We follow Chu and Cozzi (2014) to remove the scale effects by assuming $\lambda_t\,(j) = \varphi \frac{L_{r,t}(j)}{L}$. The aggregate arrival rate of innovation is

$$\lambda_t = \int_0^1 \lambda_t\,(j)\, dj = \varphi \frac{L_{r,t}(j)}{L} = \varphi l_{r,t}, \tag{15}$$

where $l_{r,t}$ is the share of population employed in R&D. Similarly, the share of population in production is $l_{x,t} = L_{x,t}/L$.

With R&D subsidies from seigniorage (i.e., $S_t = \beta R_t$), the profit of entrepreneurship, $\widehat{\Pi}_t$, becomes

$$\widehat{\Pi}_t = \Pi_t\,(j) + S_t = \left(\frac{\gamma-1}{\gamma}\right) y_t + \beta\,(g_t + \pi_t)\,\phi_t y_t. \tag{16}$$

The no-arbitrage condition for v_t is

$$r_t v_t = \widehat{\Pi}_t + \dot{v}_t - \lambda_t v_t. \tag{17}$$

2.5. The Labor Market and the Resource Constraint

2.5.1. The Labor Market

Consumers as workers can freely choose to work in manufacturing or R&D. The labor market clearing condition is

$$\int_0^1 L_{x,t}(n)dn + \int_0^1 L_{r,t}(j)dj = L_{x,t} + L_{r,t} = l_t L, \tag{18}$$

where $L_{x,t}$ and $L_{r,t}$ are the employment in manufacturing and R&D, respectively.

2.5.2. The Resource Constraint

The resource constraint needs careful derivation. The resource constraint is always $y_t = c_t L$, even if some seigniorage revenue is used to subsidize entrepreneurs. The derivation is as follows. Plugging $\tau_t = R_t/L = \left(\dot{m}_t + \pi_t m_t\right)$ back into (2) yields the resource constraint of the economy: $\dot{a}_t = r_t a_t + w_t l_t - c_t - \beta\tau_t$. Using $v_t = a_t L$ and $l_t = l_{x,t} + l_{r,t}$, the resource constraint becomes $\dot{v}_t/L = r_t v_t/L + w_t\left(l_{x,t} + l_{r,t}\right) - c_t - \beta\tau_t$. Using (10) to replace $w_t l_{x,t}$ and equations (14), (16) and (17) to replace $w_t l_{r,t}$, we have $\frac{\dot{v}_t}{L} = \frac{r_t v_t}{L} + \frac{y_t}{\gamma L} + \frac{\left(\frac{\gamma-1}{\gamma}\right)y_t + \beta R_t + \dot{v}_t - r_t v_t}{L} - c_t - \beta\tau_t$. Therefore, the final goods market clearing condition is $c_t = y_t/L$.

2.6. The General Equilibrium and the Balanced Growth Path

We can now define the general equilibrium of our model.

Definition 2.1. The general equilibrium of our model is a time path of prices $\{p_t(n), r_t, w_t, i_t, v_t\}$ and allocations $\{c_t, m_t, y_t, x_t(n), L_{x,t}(n), L_{r,t}(j)\}$, which satisfy the following conditions at each instant of time: households maximize utility taking prices $\{r_t, w_t, i_t\}$ as given; competitive final-goods firms maximize profit taking $\{p_t(n)\}$ as given; monopolistic intermediate-goods firms choose $\{L_{x,t}(n), p_t(n)\}$ to maximize profit taking $\{w_t\}$ as given; R&D firms choose $\{L_{r,t}(j)\}$ to maximize expected profit taking $\{w_t, i_t, v_t\}$ as given; the labor market clears (that is, $L_{x,t} + L_{r,t} = l_t L$); the final goods market clears (that is, $y_t = c_t L$); the value of monopolistic firms adds up to the value of households' assets (i.e., $v_t = a_t L$).

Plugging equation (9) into (7), we have

$$y_t = \exp\left(\int_0^1 N_t(n)\,dn \ln\gamma\right) L_x = \exp\left(\int_0^t \lambda_v dv \ln\gamma\right) L_x = Z_t L_x, \quad (19)$$

where $Z_t \equiv \exp\left(\int_0^t \lambda_v dv \ln\gamma\right)$ is the level of aggregate technology. The growth rate of Z_t is

$$g_z = \lambda_t \ln\gamma = \varphi l_{r,t} \ln\gamma. \quad (20)$$

Proposition 1. *Given a fixed nominal interest rate (i.e., $i_t = i$), the dynamics of the economy is that the economy immediately jumps to a unique and saddle-point stable balanced growth path on which each variable grows at a constant rate.*

Proof. See Appendix A. ▌

On the balanced growth path, equation (19) yields $g_y = g_z$, given no population growth. Per capita consumption is $c_t = y_t/L$, which yields $g_c = g_z$. The binding CIA constraint means $g_c = \dot{m}_t/m_t$. Therefore, the balanced growth rate g_t is given in (20).

Given a nominal interest rate i, we can solve for the equilibrium labor allocation (and all the other endogenous variables). Substituting $\dot{v}_t/v_t = g = r - \rho$ into (17) and then using (14), we have $\lambda\widehat{\Pi}_t = (\rho + \lambda)\, w_t L_{r,t}$. Then using (10), (16), (15) and $(g_t + \pi_t) = (i - \rho)$, we have

$$[(\gamma - 1) + \beta\gamma\,(i - \rho)\,\phi]\, l_x = l_r + \rho/\varphi. \quad (21)$$

We have $y_t = c_t L$. Using the binding CIA constraint $c_t = m_t$, we have $\phi_t = L m_t / y_t = 1$.

The labor market clearing condition is

$$l_r + l_x = l = 1 - \theta\gamma\,(1 + i_t)\, l_x. \quad (22)$$

Using $\phi_t = 1$ and solving (21) and (22) yields the stationary equilibrium labor allocation:

$$l_r = \frac{(\gamma - 1) + \beta\gamma\,(i - \rho)}{\gamma\,[1 + \beta\,(i - \rho) + \theta\,(1 + i)]}\left(1 + \frac{\rho}{\varphi}\right) - \frac{\rho}{\varphi}, \quad (23)$$

$$l_x = \frac{1}{\gamma\,[1 + \beta\,(i - \rho) + \theta\,(1 + i)]}\left(1 + \frac{\rho}{\varphi}\right), \quad (24)$$

$$l = \frac{1 + \beta\,(i - \rho)}{1 + \beta\,(i - \rho) + \theta\,(1 + i)}\left(1 + \frac{\rho}{\varphi}\right) - \frac{\rho}{\varphi}. \quad (25)$$

2.7. Central Bank Independence and the Inflation Rate

We focus on second-best allocations. We impose balanced growth on (1) to obtain

$$U = \frac{1}{\rho}\left[\ln\left(Z_0 l_x\right) + \frac{g}{\rho} + \theta \ln\left(1-l\right)\right] = \frac{1}{\rho}\left[\ln\left(l_x\right) + \frac{g}{\rho} + \theta \ln\left(1-l\right)\right], \quad (26)$$

where the last equality is obtained by normalizing Z_0 (the aggregate technology at time 0) to unity (following Chu and Cozzi, 2014).

2.7.1. Inelastic labor supply

Under inelastic labor supply (i.e., $\theta = 0$), the equilibrium labor allocations become

$$l_r = \frac{(\gamma-1)+\beta\gamma\left(i-\rho\right)}{\gamma\left[1+\beta\left(i-\rho\right)\right]}\left(1+\frac{\rho}{\varphi}\right) - \frac{\rho}{\varphi}, \quad (27)$$

$$l_x = \frac{1}{\gamma\left[1+\beta\left(i-\rho\right)\right]}\left(1+\frac{\rho}{\varphi}\right), \quad (28)$$

$$l = 1. \quad (29)$$

PROPOSITION 2. *Under inelastic labor supply and* $\frac{\beta\varphi \ln\gamma\left(1+\frac{\rho}{\varphi}\right)}{\gamma} \leq 1$, *when the step-size of innovation* γ *is small, a higher degree of CBI increases the optimal nominal interest rate and thereby the inflation rate; when it is large, a higher degree of CBI would decrease the optimal nominal interest rate and thereby the inflation rate.*

Proof. Now plugging the equilibrium labor allocations in (27)-(29) into (26) and taking the derivative with respect to the nominal interest rate, we have

$$\frac{\partial U}{\partial i} = \frac{\beta}{\gamma\rho}\left[\frac{\left(1+\varphi/\rho\right)\ln\gamma - \gamma\left[1+\beta\left(i-\rho\right)\right]}{\left[1+\beta\left(i-\rho\right)\right]^2}\right]. \quad (30)$$

Solving $\frac{\partial U}{\partial i} = 0$ yields the optimal interest rate as

$$i^* = \rho + \frac{\left(1+\varphi/\rho\right)\ln\gamma - \gamma}{\gamma\beta}, \text{ if } 1 < \left(1+\varphi/\rho\right)\frac{\ln\gamma}{\gamma}, \quad (31)$$

$$i^* = \rho - \frac{\gamma - (1 + \varphi/\rho)\ln\gamma}{\gamma\beta}, \text{ if } 1 > (1 + \varphi/\rho)\,\frac{\ln\gamma}{\gamma}. \tag{32}$$

The optimal interest rate depends on the size of the structural parameters (e.g., β and γ). The step-size of innovation γ is assumed to be larger than 1. Therefore, when γ is small (approaching 1), we have $(1 + \varphi/\rho)\,\frac{\ln\gamma}{\gamma} < 1$. In this case, the optimal interest rate would be the one given in (32), and we have $i^* < \rho$. In this case, the optimal interest rate could be negative and the Friedman rule (Friedman, 1969) will be optimal if we respect the zero lower bound on the nominal interest rate. $(\ln\gamma)/\gamma$ is an increasing function of γ when $\ln\gamma \leq 1$. When γ is large (approaching 2.71828), we may have $(1 + \varphi/\rho)\,\frac{\ln\gamma}{\gamma} > 1$. In this case, the optimal interest rate would be the one given in (31), and we have $i^* > \rho$.

According to (31), the optimal nominal interest rate decreases with β (the degree of CBI) when γ is large. By contrast, (32) indicates that the optimal interest rate increases with β when γ is small. Additionally, when the Friedman rule is optimal, initially an increase in β has no effect on the nominal interest rate. However, when β is above a threshold, its further increase will raise the optimal nominal interest rate.

On the balanced growth path, we have $\pi = i^* - g(i^*) - \rho$. Given an increase in the nominal interest rate, we have

$$g'(i^*) = \frac{\varphi\ln\gamma}{\gamma}\frac{\beta}{[1 + \beta(i - \rho)]^2}\left(1 + \frac{\rho}{\varphi}\right), \tag{33}$$

which shows $g'(i^*) < 1$ if $\frac{\beta\varphi\ln\gamma\left(1+\frac{\rho}{\varphi}\right)}{\gamma} \leq 1$, and there is a positive relationship between the nominal interest rate and the inflation rate.

When γ is large, the optimal interest rate given in (31) indicates that it decreases with β. As a result, the inflation rate also decreases. That is, a higher degree of CBI decreases the optimal nominal interest rate, ending up decreasing the inflation rate. We would observe a negative relationship between CBI and the inflation rate.

When γ is small, the optimal interest rate given in (32) indicates that it increases with β. In other words, a higher degree of CBI increases the optimal nominal interest rate. In this case, given $\pi = i^* - g(i^*) - \rho$, the inflation rate would also increase. Therefore, in this case a higher degree of CBI would increase the inflation rate. ▌

The economic intuition behind Proposition 1 is as follows. We have introduced the assumption that a higher degree of CBI means a larger share of the seigniorage revenue would be used to subsidize productivityenhancing activities. A higher nominal interest rate would yield larger seigniorage revenue. When a larger share of the seigniorage revenue is allocated to entrepreneurs, it would increase R&D labor l_r. When the step-size of innovation is small, there is R&D overinvestment (because the business stealing effect dominates the intertemporal spillover effect and the appropriability effect, which is more likely when γ is small, see Aghion and Howitt, 1992, and Chu and Cozzi, 2014). In this case, the optimal interest rate would be smaller than ρ, according to (32). When this happens, there would be negative seigniorage revenue, which means the entrepreneurs are taxed by the low nominal interest rate. A resultant decrease in R&D labor l_r would be welfare-improving when there is R&D overinvestment. When the step-size of innovation is large, there is R&D underinvestment. In this case the optimal interest would be above ρ (according to (31)), yielding positive seigniorage revenue. The positive seigniorage revenue allocated to entrepreneurs would increase R&D labor, which is welfare-improving when there is R&D underinvestment.

According to (26), an increase in the nominal interest rate has two opposing effects on the welfare. On the one hand, it increases R&D labor l_r and thereby the growth rate g through the seigniorage effect. This would increase welfare. On the other hand, manufacturing labor l_x decreases when R&D labor increases, ultimately decreasing welfare. We can view the seigniorage effect as the marginal benefit of an increase in the nominal interest rate. According to the numerator in (30), the marginal cost is mainly related to the step-size of innovation. For optimality (i.e., maximizing welfare), given a fixed marginal cost, the marginal benefit has to remain unchanged. An increase in the degree of CBI increases the marginal benefit of an increase in the nominal interest rate. When the step-size of innovation is small, the optimal nominal interest rate must increase. An increase in the nominal interest rate, when it is below ρ, would increase the seigniorage and thereby decrease the seigniorage effect (considering the seigniorage revenue $R_t = (i - \rho)\, y_t$). When the step-size of innovation is high, the nominal interest rate is above ρ. An increase in the degree of CBI would cause the optimal nominal interest rate to decrease. A decrease in the nominal interest rate when it is above ρ would decrease the seigniorage and, therefore, the seigniorage effect.

2.7.2. Elastic labor supply

Elastic labor supply introduces an additional distortion of a positive nominal interest rate on welfare—the effect of a smaller market size. That is, a higher nominal interest rate decreases total labor supply via the consumption-leisure choice, thereby decreasing both R&D labor l_r and manufacturing labor l_x. Proposition 2 holds with more restrictive parameter space (e.g., when θ is low). When θ is high, CBI has a positive effect on inflation even when the step-size of innovation is large (see the calibration results in section 2.9). The economic intuition can be seen using (26). Under elastic labor supply, the labor-leisure choice from a higher nominal interest rate means labor supply decreases with a higher nominal interest rate (the small market size effect). As a result, both R&D labor l_r and manufacturing labor l_x decrease, incurring an additional welfare loss. However, the last-term in (26) captures the welfare gain from more leisure. An optimal nominal interest rate now takes into account the additional welfare loss versus the welfare gain. Nevertheless, a higher degree of CBI increases the positive seigniorage effect that promotes welfare (and this effect dominates other effects), thereby increasing the optimal level of interest rate. Therefore, for a given high level of θ, a higher degree of CBI is associated with a higher level of nominal interest rate. The advanced countries may have high levels of θ, whereas the developing and poorer countries may have low and lower levels of θ.

2.8. Alternative Ways of Introducing CBI

There are other ways to model the role of CBI in the determination of the optimal nominal interest rate and, thus, the inflation rate. For instance, we can assume that entrepreneurs and the government share the seigniorage revenue. We can also assume that the households and the government share the seigniorage revenue. In both cases, a higher degree of CBI would tie the grabbing hand of the government, leading to a larger share of the seigniorage revenue being allocated to entrepreneurs or households.

2.8.1. Seigniorage allocated between entrepreneurs and the government

In this section, we assume that the entrepreneurs and the government get β and $(1-\beta)$ share of the seigniorage revenue. With inelastic labor supply and a CIA on consumption, the labor market clearing condition is

$$l_{r,t} + l_{x,t} + l_{g,t} = 1, \tag{34}$$

where the share of labor employed in the government sector $l_{g,t} = L_{g,t}/L$ is determined by $w_t L_{g,t} = (1-\beta) R_t$.

In general, the resource constraint is $y_t = c_t L + G_t$, when government expenditures are treated as government consumption of final goods. However, throughout this paper, we make a different assumption concerning government spending. We follow He and Zou (2016) to assume that the seigniorage revenue retained by the government will hire away more labor (the *government crowding-out effect*). He and Zou (2016, p. 474) rationalize the assumption as follows: "The government uses the seigniorage revenue that it keeps for government expenditures. Unlike the usual assumption of treating government expenditures as government consumption of final goods, we assume that government expenditures require the use of labor for the production of nonproductive and nonutility-enhancing government goods and services."

The resource constraint of the economy becomes $\dot{a}_t = r_t a_t + w_t l_t - c_t - \tau_t$. Using the new labor market clearing condition, we have $\dot{v}_t/L = r_t v_t/L + w_t\left(l_{x,t} + l_{r,t} + l_{g,t}\right) - c_t - \tau_t$. Repeating similar steps, we have $\frac{\dot{v}_t}{L} = \frac{r_t v_t}{L} + \frac{y_t}{\gamma L} + \frac{\left(\frac{\gamma-1}{\gamma}\right)y_t + \beta R_t + \dot{v}_t - r_t v_t}{L} + \frac{(1-\beta)R_t}{L} - c_t - \tau_t$. Therefore, the final goods market clearing condition is still $c_t = y_t/L$.

Therefore, the money-output ratio ϕ_t is still $\phi_t = 1$. The equilibrium labor allocation is

$$l_r = \frac{(\gamma-1)+\beta\gamma\,(i-\rho)}{\gamma\,[1+(i-\rho)]}\left(1+\frac{\rho}{\varphi}\right) - \frac{\rho}{\varphi}, \tag{35}$$

$$l_x = \frac{1}{\gamma\,[1+(i-\rho)]}\left(1+\frac{\rho}{\varphi}\right), \tag{36}$$

$$l_g = \frac{(1-\beta)\,(i-\rho)}{[1+(i-\rho)]}\left(1+\frac{\rho}{\varphi}\right). \tag{37}$$

PROPOSITION 3. *When β is large (seigniorage revenue mainly goes to entrepreneurs), the optimal nominal interest rate is above zero (i.e., the Friedman rule is sub-optimal), which increases with β. By contrast, when β is small (seigniorage revenue is mainly used to finance non-productive government spending), the Friedman rule is optimal.*

Proof. Plugging equations (35)–(37) into (26) and taking the derivative with respect to the nominal interest rate, we have

$$sign\left(\frac{\partial U}{\partial i}\right) = sign\left\{\left(1+\frac{\varphi}{\rho}\right)(\ln\gamma)\,(1-\gamma+\beta\gamma) - \gamma\,[1+(i-\rho)]\right\}. \tag{38}$$

Solving $\frac{\partial U}{\partial i} = 0$ yields the optimal interest rate as

$$i^* = \left(\rho - 1 + (1 + \varphi/\rho)\,\frac{\ln\gamma}{\gamma}\,(1 - \gamma + \beta\gamma)\right) \gtreqless 0. \tag{39}$$

According to equation (39), when β is small, it is possible that $i^* < 0$ and the Friedman rule may be optimal. When the Friedman rule is optimal, a small increase in the degree of CBI has no effect on the nominal interest rate. When β is large, the Friedman rule is sub-optimal (i.e., the optimal nominal interest rate is above zero). The cutoff value of β satisfies $\beta^* = \frac{1-\rho}{(1+\varphi/\rho)\ln\gamma} + \frac{\gamma-1}{\gamma}$.

Taking the derivative of the optimal nominal interest rate in (39) with respect to β, we have

$$\frac{\partial i^*}{\partial \beta} = (1 + \varphi/\rho)\ln\gamma > 0. \tag{40}$$

Equation (40) shows that the optimal interest rate increases with β. ▮

Therefore, when the seigniorage is more likely to be used to subsidize entrepreneurs, a condition that is more likely in developed countries with a high degree of CBI, CBI has a positive effect on the nominal interest rate. The assumption here differs from that in section 2.7.2. In section 2.7.2, the taste for leisure determines the sign of the effect of CBI on inflation: when the taste for leisure is high, CBI is more likely to have a positive effect on the nominal interest rate and thereby inflation; when it is low, CBI is more likely to have a negative effect on the nominal interest rate. Here, the allocation of the seigniorage revenue between the government and entrepreneurs determines the sign of the effect of CBI on inflation. When the majority of the seigniorage revenue is used to finance non-productive government spending, the Friedman rule is optimal and CBI has no effect on the nominal interest rate; when the seigniorage revenue is mainly channelled to subsidize business-promoting activities (i.e., the entrepreneurs), CBI has a positive effect on the nominal interest rate.

2.8.2. Seigniorage allocated between households and the government

In this case, households and the government receive α and $(1-\alpha)$ share of the seigniorage revenue, respectively. Under inelastic labor supply, both R&D labor and manufacturing labor are decreasing in the nominal interest rate. It can be shown that the Friedman rule would be optimal under the CIA constraint on consumption. There would be no room for CBI to affect the optimal nominal interest rate. However, if we follow Chu and Cozzi (2014) to assume that the CIA constraint applies to R&D investment instead of consumption (i.e., the CIA constraint becomes $b_t \leq m_t$, where b_t is the amount of money borrowed by entrepreneurs), then R&D overinvestment in equilibrium is a necessary and sufficient condition for Friedman rule to be suboptimal. When there exists R&D overinvestment, the optimal nominal interest rate would be positive. Moreover, it can be shown that the optimal nominal interest rate would also depend on the degree of CBI. In this case with inelastic labor supply, we have

$$(\gamma - 1)\, l_x = (1 + i)\,(l_r + \rho/\varphi)\,. \tag{41}$$

The labor market clearing condition is still $l_r + l_x + l_g = 1$, where l_g is determined by

$$l_g = (1 - \alpha)\,(g + \pi)\,\phi\gamma l_x = (1 - \alpha)\,(g + \pi)\,l_r, \tag{42}$$

where the second equality is derived as follows. Using the binding CIA constraint on R&D investment, we have $bL = mL = w_t L_r$. Using (10), we have $\phi = mL/y = l_r/\,(\gamma l_x)$.

Now the equilibrium labor allocation becomes

$$l_r = \frac{(\gamma - 1)\left[1 + \frac{\rho}{\varphi} + (1 - \alpha)\,(i - \rho)\,\frac{\rho}{\varphi}\right]}{\gamma + i + (\gamma - 1)\,(1 - \alpha)\,(i - \rho)} - \frac{\rho}{\varphi}, \tag{43}$$

$$l_x = \frac{(1 + i)\left[1 + \frac{\rho}{\varphi} + (1 - \alpha)\,(i - \rho)\,\frac{\rho}{\varphi}\right]}{\gamma + i + (\gamma - 1)\,(1 - \alpha)\,(i - \rho)}, \tag{44}$$

$$l_g = \frac{(1 - \alpha)\,(i - \rho)\left[(\gamma - 1) - (1 + i)\,\frac{\rho}{\varphi}\right]}{\gamma + i + (\gamma - 1)\,(1 - \alpha)\,(i - \rho)}. \tag{45}$$

Plugging the labor allocations into the utility function, it is easy to see that the optimal nominal interest rate depends on α (the degree of CBI).

Therefore, we can see that capturing the second argument (i.e., an independent central bank helps to prevent the fiscal authority from financing its expenditures with the seigniorage revenue) is not sufficient for CBI to affect the optimal nominal interest rate. This is because the Friedman rule would be optimal under the CIA constraint on consumption in this case. In this case, the optimal nominal interest rate that maximizes social welfare would depend on the CBI only when the CIA constraint also applies on R&D investment.

To summarize, despite of the different modelling assumptions, our common prediction is that, CBI is more likely to have a positive effect on the nominal interest rate in developed countries, because developed countries are more likely to have a high taste for leisure and to feature that seigniorage is mainly channelled to subsidize business-promoting activities.

2.9. Quantitative Analysis

In this calibration analysis, we focus on the developed/advanced countries. Additionally, we focus on the elastic labor supply case. That is, we are using (23)-(25).

Our model has the following set of structural parameters $\{\rho, \gamma, \varphi, \theta, \beta\}$. We follow Chu et al. (2019) to set the discount rate ρ to 0.04 and the step size of innovation γ to 1.05. We need three conditions to pin down the values of $\{\varphi, \theta, \beta\}$. The first condition is the annual long-run GDP per capita growth of 1.8% in advanced countries. The second is the standard moment of $l = 0.3$. We need another condition. In Section 3, we will regress CBI on the inflation rate to test the predictions of our model. We can use regressions to recover $\frac{\partial i}{\partial CBI}$, but the computation is too messy. As an alternative, we use regressions to recover $\frac{\partial g}{\partial CBI}$ (see e.g., Chu et al., 2018; He, 2018c, for using regressions to help recover structural parameters in calibration. Please note that this regression is different from that in our empirical part), where the growth rate g is $g = (\varphi \ln \gamma)\, l_r$ and l_r is given in (23). We use the Penn World Table (PWT) 9.0 to construct the growth rate as the growth rate of annual real GDP per employment, denoted *growth*. Then we regress the growth rate on CBI, controlling for conditional convergence, the other important variables, and fixed time effects (see Section 3 for details). The IV regression results (see Section 3.3 for the details) for developed countries are as follows:

$$growth_t = 0.0165 \times CBI_t + (Controls)_t + T_t + \varepsilon_t, \tag{46}$$

where *Controls* are the other explanatory variables (explained in Section 3), and T_t stands for the year fixed effects. Therefore, we take the predicted value of 0.0165 for $\frac{\partial g}{\partial CBI}$. Now we pin down the values of $\{\varphi, \theta, \beta\}$ by solving the following three equations:

$$g = (\varphi \ln \gamma)\, l_r = 0.018, \tag{47}$$

$$l = 0.3, \tag{48}$$

$$\frac{\partial g}{\partial \beta} = \frac{\partial g}{\partial CBI} = 0.0165, \tag{49}$$

where l_r in (47) is given in (23); l in (48) is given in (25).[3]

We also have $i = 0.083$, which is our calculated sample value because $i = \pi + r = \pi + \rho + g$ (our sample mean of inflation rate is 2.51% for developed countries). Solving equations (47)–(49) yields the values of $\{\varphi, \theta, \beta\}$ to be $\{26.59, 2.15, 0.083\}$. According to the calibration results of Table 1, when the step-size of innovation γ is below 1.0049, the Friedman rule is optimal. The optimal nominal interest rate is positive when the step-size of innovation γ is larger than 1.0049. Additionally, the optimal nominal interest rate increases with the step-size of innovation γ.

TABLE 1.

Calibration Results

	1.1	1.2	1.3	1.4	1.5
	$\{\rho, \varphi, \theta, \beta\} = \{0.04, 26.59, 2.15, 0.083\}$				
	$\gamma \leq 1.0049$	$\gamma = 1.01$	$\gamma = 1.02$	$\gamma = 1.03$	$\gamma = 1.05$
i^*	0	12.0%	33.5%	51.3%	73.7%

Note: i^* is the optimal nominal interest rate.

In fact, a wide range of plausible values for nominal interest rates in advanced economies, such as the US, lies between 0% and 16%. The optimal nominal interest in Table 1 is much higher. The reason is discussed in the footnote: the increase in the degree of CBI may not cause a one-to-one increase in the share of seigniorage allocated to entrepreneurs. Therefore, it is meaningful for us to take different values of $\frac{\partial \beta}{\partial CBI}$ and thereby $\frac{\partial g}{\partial \beta} = \frac{\partial g}{\partial CBI} / \frac{\partial \beta}{\partial CBI} = 0.0165 / \frac{\partial \beta}{\partial CBI}$ in (49) to re-evaluate the effects. We find that when $\frac{\partial \beta}{\partial CBI}$ is below 0.93, there will be no solutions. Therefore, we take the following values of $\frac{\partial \beta}{\partial CBI}$: 0.95, 0.96, 0.962, 0.965, 0.968. The calibration results are presented in Table 2. With lower $\frac{\partial \beta}{\partial CBI}$, the calibrated value of β becomes smaller, so does the optimal nominal interest rate. Now the optimal nominal interest rates are around the values observed in real world situations.

The intuition behind the results in Table 2 is that, under elastic labor supply and the CIA on consumption, monetary expansion would decrease

[3]We have taken a short-cut here concerning (49). The reason is that β is a proxy for CBI (or vice versa), but they are not the same thing. We have $\frac{\partial g}{\partial CBI} = \frac{\partial g}{\partial \beta} \frac{\partial \beta}{\partial CBI}$. If we have $\frac{\partial \beta}{\partial CBI}$, we can recover $\frac{\partial g}{\partial \beta} = \frac{\partial g}{\partial CBI} / \frac{\partial \beta}{\partial CBI}$. However, we do not have the necessary data on the share of the seigniorage revenue allocated to entrepreneurs across countries (i.e., $\frac{\partial \beta}{\partial CBI}$). Therefore, we have used the implicit assumption $\frac{\partial \beta}{\partial CBI} = 1$ in (49). Nevertheless, we will take different values of $\frac{\partial \beta}{\partial CBI}$ and thereby $\frac{\partial g}{\partial \beta}$ for calibration.

growth and welfare under the traditional assumption that the seigniorage revenue is lump-sum transferred to households. That is, the optimal nominal interest rate should be zero (respecting the zero lower bound) under elastic labor supply and the CIA on consumption. Monetary expansion cannot be welfare improving unless CBI ensures part of the seigniorage revenue is used to subsidize entrepreneurs. In other words, a positive nominal interest rate would be optimal only when the CBI can ensure some share of the seigniorage revenue is used as R&D subsidies. A higher degree of CBI may result in a larger share of the seigniorage revenue used as R&D subsidies, and the optimal nominal interest rate would increase.

TABLE 2.

Calibration Results

	2.1	2.2	2.3	2.4	2.5
	$\frac{\partial\beta}{\partial CBI}= 0.95$	$\frac{\partial\beta}{\partial CBI}= 0.96$	$\frac{\partial\beta}{\partial CBI}= 0.962$	$\frac{\partial\beta}{\partial CBI}= 0.965$	$\frac{\partial\beta}{\partial CBI}= 0.968$
	$\{\rho,\gamma\} = \{0.04, 1.05\}$, $\{\varphi,\theta,\beta\} =$				
	$\{27.9, 2.1, 0.024\}$	$\{27.6, 2.1, 0.036\}$	$\{27.6, 2.1, 0.039\}$	$\{27.5, 2.1, 0.042\}$	$\{27.4, 2.1, 0.046\}$
i^*	0%	1.14%	4.56%	9.76%	15.1%

Note: $i^*$is the optimal nominal interest rate.

3. EMPIRICAL EVIDENCE

In the following we empirically test the prediction of our model. However, the nominal interest rate is difficult to observe across countries. In contrast, data on the rate of inflation is widely accessible and reliable. Because the inflation rate is determined by the nominal interest rate through the Fisher equation (Proposition 2 has proved that there is a positive relationship between the nominal interest rate and the inflation rate), we test the effect of CBI on the inflation rate.

3.1. Empirical Specification

We use the following empirical specification:

$$\pi_{it} = \beta_1\pi_{i,t-1} + \beta_2 CBI_{i,t} + \beta_3(Controls) + \theta_i + T_t + \varepsilon_{it}, \quad (50)$$
$$\log(1+\pi)_{it} = \beta_1 \log(1+\pi)_{i,t-1} + \beta_2 CBI_{i,t} + \beta_3(Controls) + \theta_i + T_t + \varepsilon_{it}, \quad (51)$$

where π_{it} is the average annual rate of inflation at year t for country i, and CBI stands for the degree of CBI.[4] *Controls* are the other explanatory

[4]It is also worth mentioning that in our empirical specification, we have used the current value of CBI. Nevertheless, our results remain robust when we used the lagged value of CBI to mitigate the simultaneity problem in the previous version of the paper.

variables (explained below). θ_i and T_t stand for the country fixed effects and year fixed effects, respectively.

Existing studies have used several transformed measures of the inflation. For instance, some researchers have used the logarithm of (1+inflation rate) (see Dincer and Eichengreen, 2014). To be comparable with existing studies, we will use the logarithm of (1+inflation rate) as the dependent variable. Nevertheless, we will check the robustness of our results by using the change in Consumer Price Index (CPI) as the measure of inflation.

There is no prior about whether we should control for the lagged dependent variable in the regressions. However, according to the Phillips curve, inflation would depend on its past value (one can explain this as adaptive expectation). Therefore, it is possible that changes in inflation rates are persistent over time. With the lagged dependent variable included, the dynamic panel data specification will allow us to use the most efficient system GMM proposed by Blundell and Bond (1998) to deal with the potential endogeneity of CBI and all the other independent variables, using internal instruments (see elaboration in Roodman, 2006). Nevertheless, we have checked the robustness of our results by using the static specification and using legal origins as instruments.

To get more control variables to avoid the potential omitted variable bias, we follow the Phillips curve literature. According to the Phillips curve, inflation would also depend on the output gap (the difference between output and its potential). At any point of time, potential output is assumed to be fixed; therefore, inflation would then depend on the factors impacting output. Thus, we control for output per capita (e.g., Dincer & Eichengreen, 2014). Output per capita is included because advanced and developed countries on average have lower levels of inflation. To mitigate its potential endogeneity problem, we use the lagged value of output per capita. That is, we control for $\ln\left(\frac{GDP}{emp}\right)_{t-1}$, the logarithm of real GDP per employment for the previous year. We also control for factors that may impact output. Specifically, we control for I/GDP and $Human$, the physical capital investment rate and human capital indicator, respectively. The control variable *labor* measures labor force growth. The level of government spending may also have an effect on the inflation rate, and we include the ratio of government spending to GDP ratio, denoted GOV/GDP, in the regression.

The existing literature also offers a standard set of variables that explain inflation differences across countries. These variables include trade openness and financial depth. Therefore, we further control for the share of current account surplus to GDP, denoted CA/GDP, and financial depth, denoted FD/GDP. There is no theoretical explanation for trade openness to impact the inflation rate. However, the current account status may have an impact on it. A country having a current account deficit may have experienced an economic downturn, raising people's expectation of inflation and, in this way, the real inflation rate.

The data sample and the measures of explanatory variables are important but not closely related to the empirical results. Therefore, we put the descriptions in Appendix C. Table 3 reports the summary statistics of the inflation rate in our sample.

TABLE 3.

Descriptive Statistics

	Observations	Mean	Standard deviation	Minimum	Maximum
π *(%)*	854	8.75	18.82	−35.84	325.00
$\ln(1+\pi)$	836	1.78	1.00	−2.75	5.79
CBI	875	0.44	0.20	0.09	0.83
CA/GDP	884	-0.03	0.16	-0.56	0.63
$\ln(FD/GDP)$	883	3.43	1.09	0.24	5.74
$\ln(GOV/GDP)$	884	2.82	0.42	0.51	3.75
$\ln(GDP/emp)_{t-1}$	884	10.09	1.03	7.01	12.31
$\ln(Human)$	884	0.89	0.28	0.12	1.31
$\ln(I/GDP)$	884	3.01	0.38	1.40	4.13
$\ln(labor)$	866	1.89	0.50	−3.50	3.53

Note: the data are from the PWT 9.0 (unless indicated otherwise), covering 68 countries during 1998-2010. π is the inflation rate using the CPI data of IFS of IMF (in percentage term). *CBI* is the CBI measure constructed in Dincer and Eichengreen (2014). *FD/GDP* is the indicator "Domestic credit to private sector (% of GDP)" of the World Bank. *CA/GDP and GOV/GDP* are the ratios of current account and government spending to GDP, respectively. *GDP/emp* is real GDP per employment (in 2011 us$). *Human* measures human capital. *I/GDP* is the investment rate. *labor* is the employment growth. The variables are are multiplied by 100 before taking logarithms.

3.2. System GMM Estimation

Although our theory does not predict a feedback effect from inflation to CBI, inflation may have an effect on CBI by affecting growth in real world situations. As discussed, the dynamic panel data specification will allow us to use system GMM to deal with the potential endogeneity of CBI and all the other independent variables. Our model has the characteristics (especially "large N and small T") listed in Roodman (2006). Therefore, we use the most efficient system GMM estimator to establish a causal re-

TABLE 4.

System GMM Estimation betwen CBI and Inflation Dynamic Panel-Data Estimation, Two-step System GMM. Dep. vari.: $\log(1+\pi)$ during 1998-2010

	Regression number			
	2.1	2.2	2.3	2.4
	$\pi < 100$		$\pi < 50$	
Indep. Variable	all countries	developing countries	all countries	developing countries
CBI	2.53**	2.70*	2.73**	2.72*
	(1.67)	(1.50)	(1.14)	(1.48)
$\ln(1+\pi)_{t-1}$	0.41***	0.39***	0.43***	0.40***
	(0.08)	(0.10)	(0.08)	(0.11)
CA/GDP	−0.03	−0.47	−0.45	−0.73
	(0.96)	(1.28)	(0.94)	(1.10)
$\ln(FD/GDP)$	−0.11	−0.40	−0.12	−0.47
	(0.42)	(0.45)	(0.39)	(0.37)
$\ln\left(\frac{GDP}{emp}\right)_{t-1}$	−0.17	−0.13	0.20	−0.13
	(0.24)	(0.38)	(0.32)	(0.40)
$\ln(GOV/GDP)$	−0.69	−1.22*	−0.51	−1.30**
	(0.65)	(0.61)	(0.63)	(0.52)
$\ln(I/GDP)$	−0.62*	−0.70**	−0.13	−0.61*
	(0.31)	(0.27)	(0.34)	(0.24)
$\ln(Human)$	0.61	0.55	−0.14	0.73
	(1.22)	(1.49)	(0.78)	(1.39)
$\ln(labor)$	0.05	−0.03	0.10	−0.03
	(0.11)	(0.14)	(0.11)	(0.13)
Time FE	YES	YES	YES	YES
Financial Crises Dummy	YES	YES	YES	YES
Hansen OverID test (p-value)	0.16	0.38	0.16	0.61
Difference-in-Hansen (p-value)	0.17	0.30	0.23	0.29
Number of Instruments	39	39	39	39
Arellano-Bond test for AR(2)	0.18	0.42	0.16	0.41
F-test	67.12***	38.03***	62.54***	43.65***
Observations	736	595	730	589

Note: lagged dependent variables are treated as predetermined. All other variables except the time dummies are treated as endogenous. Time dummies are used as instruments. π is the inflation rate using the CPI data of IFS of IMF. *CBI* is the CBI measure in Dincer and Eichengreen (2014). *GDP/emp* is real GDP (in 2011 us $) per employment. *CA/GDP, GOV/GDP, and FD/GDP* are the ratios of current account, government spending, and domestic credit to the private sector to GDP, respectively. *I/GDP* is the investment rate. *Human* is human capital. *labor* is the employment growth. *** Significant at the 0.01 level, ** at the 0.05 level,* at the 0.10 level (corrected standard errors in parentheses)

lationship between inflation and CBI. Since we use macro-level data, it is possible that other explanatory variables may also be endogenous due to reverse causality. In using the system GMM estimation, we treat lagged variables as predetermined and the other variables as endogenous. Moreover, following Roodman (2006), the fixed country dummies are excluded, whereas the year dummies are used as exogenous instruments.

Moreover, we use the two-step system GMM estimation and take the Windmeijer (2005) correction into account. Furthermore, to make sure our results are not driven by outliers, we delete the outliers with annual inflation rates above 100% (our results remain robust without dropping the outliers, and the inflation rates in developed countries were all below 100% in our sample). The two-step system GMM estimation results are presented in Table 4.

According to Table 4, both the Hansen and the difference-in-Hansen tests confirm that the instrument set can be considered valid. The F-test shows that the overall regression is significant. The Arellano-Bond AR(2) test accepts the hypothesis of no autocorrelation of the second order. Following Roodman (2006), we have collapsed the instruments to deal with the instruments proliferation problem. Now the number of instruments is smaller than the number of groups (i.e., 68). These support system GMM estimation.

Regression 2.1 of Table 4 presents the system GMM estimation for the full sample of both advanced and developing countries. The results indicate that the estimated coefficient on CBI is positive and significant at the 5% level. Regression 2.3 of Table 4 reports the results with annual inflation below 50%. The estimated coefficient on CBI remains positive and significant at the 5% level.

3.2.1. Samples with Developing Countries

According to our theory, it may not be a good idea to put the advanced and developing countries together in a regression. This is because the advanced and developing countries may differ a lot. First, they may differ in the step-size of innovation. Second, the taste for leisure may be different. Third, the share of the seigniorage revenue in subsidizing business-promoting activities may be much larger in developed countries with a higher degree of CBI.

Therefore, it is meaningful to check whether differences exist between our results for advanced countries and those for developing ones. As discussed, our sample consists of 68 countries, among which 12 are advanced and 56 are developing. We have split the sample into two: one with 12 advanced countries and the other with 56 that are developing. The sys-

TABLE 5.

System GMM Estimation betwen CBI and Inflation Dynamic Panel-Data Estimation, Two-step System GMM. Dep. vari.: π during 1998-2010

	Regression number			
	3.1	3.2	3.3	3.4
	$\pi < 100$		$\pi < 50$	
Indep. Variable	all countries	developing countries	all countries	developing countries
CBI	27.55*	47.29	32.37	59.48
	(15.19)	(40.70)	(19.99)	(41.27)
π_{t-1}	0.67***	0.61***	0.78***	0.70***
	(0.12)	(0.15)	(0.18)	(0.19)
CA/GDP	10.00	16.01	22.21	23.94
	(13.74)	(19.36)	(22.73)	(20.56)
$\ln(FD/GDP)$	4.64	5.67	6.08	7.69
	(3.50)	(5.41)	(4.56)	(5.63)
$\ln\left(\frac{GDP}{emp}\right)_{t-1}$	−0.84	0.32	−4.06	−3.50
	(4.10)	(7.09)	(5.96)	(8.40)
$\ln(GOV/GDP)$	−4.68	−0.82	−2.67	0.19
	(4.85)	(7.09)	(8.01)	(8.39)
$\ln(I/GDP)$	8.58	8.70	8.77	6.98
	(6.37)	(7.35)	(6.26)	(6.93)
$\ln(Human)$	−3.75	−4.49	2.86	3.56
	(12.33)	(16.43)	(14.09)	(18.92)
$\ln(labor)$	5.07	3.81	8.95	11.06
	(5.62)	(11.13)	(9.27)	(14.18)
Time FE	YES	YES	YES	YES
Financial Crises Dummy	YES	YES	YES	YES
Hansen OverID test (p-value)	0.86	0.64	0.83	0.71
Number of Instruments	30	30	30	30
Arellano-Bond test for AR(2)	0.65	0.69	0.73	0.68
F-test	28.03***	24.89***	12.33***	16.15***
Observations	765	622	759	616

Note: lagged dependent variables are treated as predetermined. All other variables except the time dummies are treated as endogenous. Time dummies are used as instruments. π is the inflation rate using the CPI data of IFS of IMF. *CBI* is the CBI measure in Dincer and Eichengreen (2014). *GDP/emp* is real GDP (in 2011 us \$) per employment. *CA/GDP, GOV/GDP, and FD/GDP* are the ratios of current account, government spending, and domestic credit to the private sector to GDP, respectively. *I/GDP* is the investment rate. *Human* is human capital. *labor* is the employment growth.
*** Significant at the 0.01 level, ** at the 0.05 level, * at the 0.10 level
(corrected standard errors in parentheses)

tem GMM estimation usually applies to samples with "large N and small T". Therefore, we only report the results with the sample of 56 developing countries. The results in regression 2.2 of Table 4 indicate that the estimated coefficient on CBI is positive and significant at the 10% level in the sample of developing countries. Regression 2.4 indicates that the results remain robust when using the sample with annual inflation below 50%.

3.2.2. Using the Inflation Rate as the Dependent Variable

We have also checked the results with the change in CPI as the dependent variable. The system GMM estimation results are presented in Table 5. This table shows that both the Hansen and the difference-in-Hansen tests confirm that the instrument set can be considered valid. The F-test indicates that the overall regression is significant. The Arellano-Bond AR(2) test accepts the hypothesis of no autocorrelation of the second order. Following Roodman (2006), we have collapsed the instruments to deal with the instrument proliferation problem. Now the number of instruments is smaller than the number of groups (i.e., 68). These support system GMM estimation.

Regression 3.1 of Table 5 presents the system GMM estimation for the full sample of both advanced and developing countries. The results indicate that the estimated coefficient on CBI remains positive and significant at the 10% level. Regression 3.3 of Table 5 reports the results with annual inflation below 50%. The estimated coefficient on CBI remains positive but becomes insignificant at the 10% level. The results in regression 3.2 of Table 5 indicate that the estimated coefficient on CBI is positive and insignificant at the 10% level in the sample of developing countries. The results remain robust when use the sample with annual inflation below 50% (see regression 3.4).

3.3. IV Estimation

There may be a large difference between the *de jure* and the *de facto* measures of CBI, especially in developing countries. As the *de jure* measure of CBI may be related to the rule of law in a country, here we use static panel data and legal origins as instruments in IV regressions to check the robustness of our results.

We get the data on "The Quality of Government" by La Porta et al. (1999). To do so, we accessed http://scholar.harvard.edu/shleifer/publications/quality-government to acquire the data on legal origins. The legal origins are represented by five dummy variables — *legor_uk, legor_fr, legor_so, legor_ge,* and *legor_sc*, — meaning that the legal origins are British, French, Socialist, German, and Scandinavian, respectively. The data on legal origins cover years before

1997. Because these data on legal origins have no time dimension, we cannot control for fixed country effects. We still control for fixed year effects.

Table 6 presents the first-stage results of the 2SLS (two-stage least squares) estimation. According to regression 4.1 of Table 6, legal origins have significant effects on CBI during 1998–2010. Regressions 4.2 and 4.3 indicate that the instruments also have significant effects on CBI in advanced and developing countries, respectively. The values of the F-test statistics on the excluded instruments are all much larger than 10. Therefore, the instruments are strong according to Staiger and Stock (1997), and we use 2SLS estimation.

TABLE 6.

2SLS Regressions annual inflation $\pi < 100$) First-stage results (first-stage dep. vari. *CBI* 1998-2010)

	Regression number		
	4.1	4.2	4.3
	Sample		
Indep. Variable	all countries	rich countries	poor countries
legor_uk	-0.31^{***}	-0.39^{***}	-0.26^{***}
	(0.03)	(0.03)	(0.02)
legor_fr	-0.14^{***}		-0.11^{***}
	(0.03)		(0.02)
legor_so	-0.05		
	(0.03)		
legor_ge	-0.23^{***}	-0.57^{***}	
	(0.04)	(0.06)	
Time fixed effects	YES	YES	YES
F-test on excluded instruments	F(4,783)=100	F(2,130)=104	F(2,633)=135
(prob.>F)	(0.00)	(0.00)	(0.00)
R^2(centered)	0.50	0.73	0.48
Observations	807	152	655

Note: *legor_uk, legor_fr, legor_so, legor_ge, and legor_sc* mean legal origins are British, French, Socialist, German, and Scandinavian, respectively. Other variables in regression include $\ln\left(\frac{GDP}{emp}\right)_{t-1}$, $\ln(FD/GDP)$, CA/GDP, $\ln(GOV/GDP)$, $\ln(I/GDP)$, $\ln(Human)$, and $\ln(labor)$.
*** Significant at the 0.01 level, ** at the 0.05 level, * at the 0.10 level
(standard errors in parentheses)

The corresponding second-stage results of the 2SLS estimation are presented in Table 7. Regression 5.1 of Table 7 indicates that the estimated coefficient on CBI is insignificant, meaning CBI has no significant, causal effect on inflation in the full sample. The Sargan overidentification tests yield a p-value above 10%, meaning the instruments are valid.

TABLE 7.

2SLS Regressions (Second-Stage Results) Second-stage dependent variable: annual inflation π 1998-2010 ($\pi < 100$)

	Regression number		
	5.1	5.2	5.3
	Sample		
Indep. Variable	all countries	rich countries	poor countries
CBI	1.21	4.27^{***}	2.03
	(2.97)	(0.99)	(3.99)
CA/GDP	2.78	-8.49^{***}	4.19
	(2.40)	(1.84)	(2.80)
$\ln(FD/GDP)$	-3.31^{***}	−0.19	−3.23
	(0.49)	(0.54)	(2.51)
$\ln\left(\frac{GDP}{emp}\right)_{t-1}$	0.53	1.05	0.71
	(0.55)	(0.64)	(0.61)
$\ln(GOV/GDP)$	−0.42	-2.47^{**}	−0.67
	(0.95)	(0.97)	(1.12)
$\ln(I/GDP)$	1.40	-1.56^{*}	1.79
	(1.00)	(0.92)	(1.17)
$\ln(Human)$	-3.44^{*}	−2.31	−3.23
	(1.98)	(2.22)	(2.51)
$\ln(labor)$	-1.63^{**}	2.13^{***}	-1.70^{**}
	(0.70)	(0.56)	(0.80)
Time FE	YES	YES	YES
Financial Crises Dummy	YES	YES	YES
Sargan test	3.57	7.05	0.75
(p-value)	(0.31)	(0.01)	(0.69)
R^2	0.18	0.36	0.14
Observations	824	153	671

Note: π is the inflation rate using the CPI data of IFS of IMF. *CBI* is the CBI measure constructed in Dincer and Eichengreen (2014). *GDP/emp* is real GDP (in 2011 us \$) per employment. *CA/GDP, GOV/GDP, I/GDP* are the ratios of current account, government spending, and investment to GDP, respectively. *Human* is human capital. *labor* is the employment growth.

*** Significant at the 0.01 level, ** at the 0.05 level, * at the 0.10 level.

(standard errors in parentheses)

When we split the full sample into advanced and developing countries, regression 5.2 of Table 7 indicates that the estimated coefficient on CBI is

TABLE 8.

2SLS Regressions (Second-Stage Results) Second-stage dependent variable: $\log(1+\pi)$ during 1998-2010 ($\pi < 100$)

Indep. Variable	Regression number 6.1 Sample: all countries	6.2 rich countries	6.3 poor countries
CBI	-0.15	1.73^{***}	-0.31
	(0.28)	(0.39)	(0.35)
CA/GDP	-0.01	-3.79^{***}	0.38
	(0.23)	(0.74)	(0.25)
$\ln(FD/GDP)$	-0.33^{***}	-0.95	-0.29^{***}
	(0.05)	(0.88)	(0.05)
$\ln\left(\frac{GDP}{emp}\right)_{t-1}$	-0.01	0.50^{*}	0.002
	(0.05)	(0.26)	(0.05)
$\ln(GOV/GDP)$	0.03	-1.50^{***}	0.02
	(0.09)	(0.39)	(0.10)
$\ln(I/GDP)$	-0.05	-0.98^{***}	-0.06
	(0.10)	(0.37)	(0.10)
$\ln(Human)$	-0.36^{*}	-0.95	-0.21
	(0.19)	(0.88)	(0.22)
$\ln(labor)$	-0.11^{*}	1.03^{***}	-0.17^{**}
	(0.07)	(0.22)	(0.07)
Time FE	YES	YES	YES
Financial Crises Dummy	YES	YES	YES
Sargan test	26.98	10.71	4.47
(p-value)	(0.00)	(0.001)	(0.11)
R^2	0.24	0.28	0.16
Observations	807	152	655

Note: π is the inflation rate using the CPI data of IFS of IMF. *CBI* is the CBI measure constructed in Dincer and Eichengreen (2014). *GDP/emp* is real GDP (in 2011 us \$) per employment. *CA/GDP, GOV/GDP, I/GDP* are the ratios of current account, government spending, and investment to GDP, respectively. *Human* is human capital. *labor* is the employment growth.
*** Significant at the 0.01 level, ** at the 0.05 level, * at the 0.10 level
(standard errors in parentheses)

positive and significant at the 1% level in advanced countries. The Sargan overidentification tests yield a p-value below 10%, meaning the instruments are invalid. This may be due to the blunt instruments problem (see Bazzi and Clemens, 2013). In contrast, regression 5.3 of Table 7 indicates that the estimated coefficient on CBI is positive and insignificant in developing countries. The Sargan overidentification tests yield a p-value above 10%, meaning the instruments are valid in developing countries.

We have checked the robustness of our results by using the logarithm of (1+inflation rate) as the dependent variable. The second-stage results of the 2SLS estimation are presented in Table 8. Regression 6.1 of Table 8 indicates that the estimated coefficient on CBI is negative and insignificant at the 10% level. One can observe that the Sargan overidentification tests yield a p-value below 10%, meaning the instruments may affect inflation through other channels (i.e., the instruments are invalid). Regression 6.2 of Table 8 indicates that the estimated coefficient on CBI is positive and significant at the 1% level in advanced countries. In contrast, regression 6.3 of Table 8 indicates that the estimated coefficient on CBI is negative and insignificant in developing countries. The Sargan overidentification tests yield a p-value above 10%, meaning the instruments are valid in developing countries.

As discussed, our results can be rationalized by our theory. When the step-size of innovation is above a threshold in all countries, the taste for leisure may be higher in developed countries. As a result, CBI would have a positive effect on the optimal nominal interest rate and, therefore, the inflation rate in advanced countries, while CBI would a negative effect on the optimal nominal interest rate and, therefore, the inflation rate in developing countries. Additionally, our results can also be rationalized by the allocation of seigniorage between government and the entrepreneurs as illustrated in Proposition 3: when the majority of the seigniorage revenue is used to finance non-productive government spending (a situation more commonly found in developing countries), the Friedman rule is optimal and CBI has no effect on the nominal interest rate; when the seigniorage revenue is mainly channelled to subsidize business-promoting activities (a condition that is more likely in developed countries,), CBI has a positive effect on the nominal interest rate.

4. CONCLUSION

There is a long-standing debate over the effect of CBI on inflation. In this paper, we first use a monetary Schumpeterian model to investigate how CBI affects inflation. We find that we cannot predict a monotone relationship between CBI and inflation. Under inelastic labor supply, when the step-size of innovation is small, CBI has a positive effect on inflation, and when the step-size of innovation is large, CBI has a negative effect on inflation. Moreover, when the taste for leisure is high and/or the seigniorage is mainly used to finance entrepreneurs, a condition that is more likely in developed countries, CBI has a positive effect on inflation; in contrast, when labor supply is inelastic and/or the seigniorage is mainly used to finance non-productive government spending, a situation more commonly found in developing countries, CBI has a negative effect or no effect on inflation.

We then test the effect of CBI on inflation. We build panel data for 68 countries during 1998–2010. We find the effect of CBI on inflation is positive and significant (at the 5% level) in system GMM estimation. Our results remain robust to the consideration of financial crises. When we split the sample into advanced and developing countries, our empirical findings match better with our prediction. The effect of CBI on inflation is positive and significant in advanced countries, and it is insignificant in developing countries in both system GMM and 2SLS estimations. Our empirical findings provide support for our theory, which also helps to resolve the debate over the effect CBI has on inflation.

A logical exercise in a formal economic modelling approach presented in the paper is attractive. The extant literature on central bank independence's impact on inflation has not used a Schumpeterian model as a framework. However, innovations depending on CBI through the seigniorage channel may seem implausible. Seigniorage, by definition, is the result of the privilege extended to central bank by the state itself. That is why seigniorage income goes back to the state, especially in the U.S.. However, even in the U.S., the FED and the role it plays also evolved over time. Institutional change in developing countries may be more drastic. Therefore, it is better we may view CBI as an evolving legal or even institutional proxy that dictates how the seigniorage is used and allocated. Scholars have studied how the central banks allocate seigniorage (see Ize, 2007). For future research, one can analyze how central banks operate and evolve in an economy, including how they allocate seigniorage, manage financial assets, and improve their own efficiency (e.g., Ize, 2007). Studies along this line would be important for us to further investigate the role of CBI in the making of monetary policy. In addition, the time dimension of the sample is not long, which is due to the source of data for CBI. Dincer and Eichengreen (2014) is an excellent source, but it may be fruitful to use other sources with longer series of data on CBI (e.g. Garriga, 2016; Romelli, 2022).

APPENDIX A
HOUSEHOLD'S DYNAMIC OPTIMIZATION

Household's Hamiltonian function is

$$H_t = \ln c_t + \theta \ln (1 - l_t) + \mu_t (r_t a_t + w_t l_t - c_t - \pi_t m_t + (1 - \beta) \tau_t) + \xi_t (m_t - c_t),$$

where μ_t is the co-state variable on (2); ξ_t is the Lagrangian multiplier for the CIA constraint. The first-order conditions include

$$\frac{\partial H_t}{\partial c_t} = \frac{1}{c_t} - \mu_t = 0, \tag{A.1}$$

$$\frac{\partial H_t}{\partial l_t} = -\frac{\theta}{1 - l_t} + \mu_t w_t = 0, \tag{A.2}$$

$$\frac{\partial H_t}{\partial a_t} = \mu_t r_t = \rho \mu_t - \dot{\mu}_t, \tag{A.3}$$

$$\frac{\partial H_t}{\partial m_t} = -\mu_t \pi_t + \xi_t = \rho \mu_t - \dot{\mu}_t. \tag{A.4}$$

Combining (A.3) and (A.4) yields $\xi_t = \mu_t (r_t + \pi_t) = \mu_t i_t$, where we define $i_t = r_t + \pi_t$. Plugging this condition into (A.1) yields

$$\frac{1}{c_t} = \mu_t (1 + i_t), \tag{A.5}$$

which is (3) in the main text. Rewriting (A.2) yields the optimal condition for labor supply

$$\frac{\theta}{1 - l_t} = w_t \mu_t, \tag{A.6}$$

which is (4) in the main text. Rewriting (A.3) as

$$-\frac{\dot{\mu}_t}{\mu_t} = r_t - \rho \tag{A.7}$$

yields the intertemporal optimality condition (6) in the main text.

APPENDIX B
PROOF OF PROPOSITION 1

Proof. We define the ratio of final output to the value of the monopolistic firms $\frac{y_t}{v_t}$ as a new transformed variable Ω_t (i.e., $\Omega_t = \frac{y_t}{v_t}$). The law of motion of Ω_t is

$$\frac{\dot{\Omega}_t}{\Omega_t} = \frac{\dot{y}_t}{y_t} - \frac{\dot{v}_t}{v_t}. \tag{B.1}$$

Given a fixed nominal interest rate i, we have $\dot{c}_t/c_t = r_t - \rho$. The final goods market clearing condition yields $\dot{y}_t/y_t = \dot{c}_t/c_t$.

Equation (17) gives $\dot{v}_t/v_t = r_t + \lambda_t - \widehat{\Pi}_t/v_t$. Equation (15) delivers $\lambda_t = \varphi l_{r,t}$. Using (16) and $\phi_t = 1$, we have $\widehat{\Pi}_t/v_t = \left(\frac{\gamma-1}{\gamma} + \beta\,(i-\rho)\right)\Omega_t$. Using these conditions, (B.1) becomes

$$\frac{\dot{\Omega}_t}{\Omega_t} = \left(\frac{\gamma-1}{\gamma} + \beta\,(i-\rho)\right)\Omega_t - \varphi l_{r,t} - \rho. \tag{B.2}$$

Combining (10), (14) and (15) yields $l_{x,t} = \frac{\Omega_t}{\varphi\gamma}$. (22) gives $l_{r,t} = 1 - [1 + \theta\gamma\,(1+i)]\,l_x$. Plugging these results into (B.2), we have

$$\frac{\dot{\Omega}_t}{\Omega_t} = [1 + \beta\,(i-\rho) + \theta\,(1+i)]\,\Omega_t - (\rho + \varphi)\,. \tag{B.3}$$

Because $\Omega_t > 0$, equation (B.3) shows that the dynamics of Ω_t is characterized by saddle-point stability such that Ω_t jumps immediately to its interior steady state which is stationary and unique. Given $l_{x,t} = \frac{\Omega_t}{\varphi\gamma}$ and $l_{r,t} = 1 - (1 + \theta\gamma\,(1+i))\,l_x$, we know that l_r, l_x and l must be stationary and unique as well.

APPENDIX C

THE DATA

For most of the other control variables, we use the recent PWT 9.0. This provides the most complete and recent data for all the countries during 1950–2014. Considering our control variables, we exclude from our sample those countries that do not have data on employment (the *emp* series in PWT 9.0) and/or human capital (the *hc* series in PWT 9.0). This leaves us with 144 countries in the sample.

For the measure on CBI, we follow the recent study of Dincer and Eichengreen (2014). They do not report the data on CBI for countries with the euro as their currency. Furthermore, some countries in Dincer and Eichengreen (2014) do not have data on employment and/or human capital. Taken together, our final sample has 68 countries with complete data. Our sample consists of both developing and developed countries. Out of these, there are 12 countries identified as advanced—namely, Australia, Canada, the United Kingdom, Iceland, Israel, Japan, the Republic of Korea, Norway, New Zealand, Singapore, Sweden, and the United States.

Because the CBI sample in Dincer and Eichengreen (2014) covers 1998–2010, we use this same period when using the current values of CBI. Therefore, our final sample, consisting of 68 countries over 1998–2010, provides a balanced panel of 884 observations. Our final sample size may be smaller, depending on the missing observations of different variables.

C.1. MEASURING THE INFLATION RATE

The inflation rate is measured as the change in CPI. The PWT 9.0 does not provide data on CPI. We acquire this data from the International Financial Statistics (IFS) of the IMF (International Monetary Fund) to obtain the data on CPI for over 100 countries (including the 68 countries in our sample) during 1950–2015.

C.2. MEASURING CENTRAL BANK INDEPENDENCE

We use the most recent data on CBI from Dincer and Eichengreen (2014) (DE hereafter). DE report updated measures of independence for more than 100 central banks during 1998–2010. DE follow Cukierman, Webb, and Neyapti (1992) (CWN hereafter) but add other aspects of CBI emphasized in the subsequent literature to measure CBI. Specifically, DE use the sixteen criteria employed by CWN and eight additional criteria (twenty-four in total, see DE, pp. 218–219 for details).

DE first aggregate their twenty-four criteria into nine as follows: "(1) The five variables regarding appointment of the CEO are aggregated into one using equal weights; (2) the four variables under policy formulation are aggregated into one using equal weights; (3) the objectives criterion stands on its own as number 3; (4–7) the first four criteria on limits on lending are each treated as a separate variable; (8) the last four criteria on limits on lending are aggregated into a single variable using equal weights; and (9) the criteria regarding board members is treated as a single variable" (DE, p. 219). Each criterion is coded on a scale of 0 (lowest degree of CBI) to 1 (highest degree of CBI). The final aggregate measure on CBI also ranges from 0 to 1 (lowest and highest degrees of CBI, respectively). DE compute two indices on CBI by aggregating the nine variables: CBIW is the weighted average of the nine aggregated variables, and CBIU is the corresponding unweighted average. Because DE report the data on CBIW, we use CBIW to measure CBI, denoted CBI. The summary statistics on CBI is presented in Table 3.

In our sample, 25 out of 68 countries experienced a change in the degree of CBI during 1998–2010 (most of the countries are developing countries, but some are advanced, developed ones—namely, Australia, the United Kingdom, Iceland, Norway, and New Zealand). As CBI does change over time, we report the results from panel data regressions. The advantage of panel data regression is that it allows us to control for fixed country effects.

C.3. MEASURING CONTROL VARIABLES

For financial depth, we have used the World Development Indicators (WDIs) of the World Bank to obtain the necessary data. Specifically, we measure financial depth (i.e., FD/GDP) as the indicator "Domestic credit to private sector (% of GDP)". Our control variable current account balance is constructed as follows. We add together the *csh_x* (the ratio of export value to GDP) and *csh_m* (the ratio of import value to GDP, the numbers are negative) series in PWT 9.0 to get the share of current account to GDP (i.e., CA/GDP). Our government spending variable is GOV/GDP, which is the ratio of government spending to GDP. We use the *csh_g* series in PWT 9.0.

According to Feenstra, Inklaar, and Timmer (2015, p. 3157), we use the $RGDP^{NA}$ series to measure real GDP. Dividing the $RGDP^{NA}$ series by the *emp* series in PWT 9.0 would yield real GDP per employment. Initial real GDP per employment (i.e., $(RGDP/emp)_{t-1}$) takes the value of the previous year. The physical and human capital investment rates (i.e., I/GDP and $Human$) are measured by the *csh_i* and *hc* series, respectively, in PWT 9.0. The labor force growth measure, *labor*, is measured as the sum of the labor force growth rate and 0.05. That is, we use 0.05 for $(g+\delta)$, which assumes a 2% world annual growth (i.e., g) and a 3% depreciation rate (i.e., δ). The labor force growth rate is measured as the annual growth of the *emp* series in PWT 9.0.

Table 3 presents the summary statistics of the final data.

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