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The Conservativeness of the Central Bank when Institutional Quality is Poor

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Abstract

We propose an extension of Alesina and Tabellini's model (1987) to include corruption, which is understood as the presence of weak institutions collecting revenue through formal tax channels. This paper analyses how conservative should an independent central bank be when the institutional quality is poor. When there are no political distortions, we show that the central bank has to be more conservative than the government, except with complete corruption. In this particular case, the central bank should be as conservative as the government. Further, we obtain that the relationship between the optimal relative degree of conservativeness of the central bank and the degree of corruption is affected by supply shocks. Concretely, when these shocks are not important, the central bank should be less conservative if the degree of corruption increases. However, this result may not hold when the shocks are relevant.

JEL classification: D6, D73, E52, E58, E62, E63.

Keywords: Central Bank Conservativeness; Corruption; Fiscal Policy; Monetary Policy; Seigniorage.

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1. Introduction

Many countries are currently being affected by a serious problem that hinders their credibility and ability to collect resources. In fact, news about corruption seem to be commonplace. Corruption is an act in which the power of public office is used for personal gain in a manner that contravenes the rules of the game (Jain, 2001). Most governments of all political shades are or have been affected by corruption scandals. Corruption can be found in bureaucracy, government ministries, managers of publicly owned resources or in general in positions with access to public funds.

The policymaker's ability to collect revenue through formal tax channels is affected by weak institutions. This may be possible through outright theft by tax officials or practices whereby tax inspectors collude with tax payers to reduce the latter's tax obligation in exchange for a bribe, as noted by Huang and Wei (2006).

It is important to note that even though we associate corruption with tax leakage, corruption can occur in many other ways, such as a large informal sector, a tradition of flouting government regulations, etc. In fact, institutional quality is one of the main causes determining the shadow economy besides other factors such as tax and social security contribution burdens, regulations, public sector services, tax morale and deterrence. Schneider and Buehn (2012) argue that the lower the quality of institutions is, the bigger the shadow economy. They show that countries like Italy and Spain have substantial shadow economies, illustrating that this phenomenon is not exclusive of developing economies.[1]

This article will analyse the implications of weak institutions for the conduct of macroeconomic policy, with the presence of an independent central banks. Crowe and Meade (2007) argue that today's central banks are more independent that they were in the 1980s. In fact, after a series of influential articles that followed Rogoff's (1985) and Alesina and Tabellini's (1987), a majority of countries have adopted independent and conservative central banks. The question that follows is, then, how conservative should the independent central bank be from society's point of view. Rogoff (1985), in a model with only one policy, obtains that society can be better off if the central bank places a greater (but not infinitely greater) weight on inflation stabilisation than society does. Alesina and Tabellini (1987) incorporate a second agent (the government) that controls fiscal policy and obtain that the welfare of the government would improve by delegating monetary policy to a slightly more conservative central bank.

Several authors have studied the effect of corruption when an independent central bank

[1] Other empirical works that analyse the effect of corruption are Fisman and Wei (2004), Javorcik and Wei (2009), among others.

is in place.[2] For instance, Jafari-Samimi and Zakeri (2001) empirically show that a more independent central bank is associated with a lower degree of corruption of public sectors. Further, Huang and Wei (2006) examine the effects of institutional quality on the desirability of several popular monetary regimes, including inflation targeting, exchange rate fixing, currency board, and a conservative central banker. However, their model differs from the one presented here in that it does not deal with stabilization issues because it abstracts from random shocks. However, Alesina and Stella (2011) argue that the shocks play an important role in crisis times. For this reason, will be considered in this article. Besides, a recent paper, Hefeker (2010), shows that the more conservative the central bank the more efforts the government will undertake to lower corruption and other forms of leakages because it can expect only little contribution from seigniorage to the budget. In our model, we also analyse the implications of corruptions in a more general setup based on Alesina and Tabellini (1987).

This paper will study how conservative should an independent central bank be, when there are two different policies (fiscal and monetary policy) in the presence of corruption. To that end, we will extend the framework developed by Alesina and Tabellini (1987) to include corruption. We will introduce an indicator of the conservativeness of the central bank that relates the weights attributed to output and public spending relative to inflation. We will show that with complete corruption, and when society has the same preferences as the government, the central bank has to be as conservative as the government. However, when the preferences of both institutions differ, the central bank should be more conservative than the government. Moreover, when the government and society have the same preferences and the shocks are important, our model departs from previous results derived in this literature (Huang and Wei, 2006).

The paper is organised as follows. Section 2 introduces the model. Section 3 studies how conservative the central bank should be when there is some degree of corruption. The conclusions are presented in the last section and proofs are gathered in the Appendix.

2. The Model

In this section, we will extend Alesina and Tabellini's model (1987) to allow for corruption.

At any period t, the output function is a simplified Lucas supply function and it is given

[2] By contrast, Faure (2011) provides a new insight into the lack of incentive from authorities to curtail corruption. He considers that the government sets inflation and taxes, assuming a dependent central bank. The main finding is that corruption can, in theory, make a country better off if its government is unable to make binding commitments and assigns a larger weight to output than to inflation stabilisation.

by

$$x_t = \pi_t - w_t - \tau_t + \varepsilon_t, \tag{2.1}$$

where x_t denotes the log of real output; π_t is the log of the price level; w_t represents the log of the nominal wage; τ_t is the tax rate on the total revenue of firms; ε_t denotes the log of the shocks. We assume that ε_t is independently and identically distributed with mean zero and variance σ_ε^2. In addition, the wage function is the following:

$$w_t = \pi^e, \tag{2.2}$$

where π^e is the expected inflation.[3]

We will introduce corruption in the model by considering that there is a connection between the government's fiscal capacity and the quality of institutions. In this way, we will follow Huang and Wei (2006), where the private sector pays a tax to the government, but only a proportion ϕ of this amount is accrued. Thus, the government budget constraint is

$$g_t = k\pi_t + \phi\tau_t, \tag{2.3}$$

where g_t represents the public spending, k denotes the degree of seigniorage $(0 \leq k \leq 1)$ and ϕ is the degree of institutional quality $(0 \leq \phi \leq 1)$. Concretely, we define the seigniorage as the revenue obtained by the government from the money creation. Often, this revenue is used by governments to finance a portion of the public spending without having to collect taxes. A low value of k signifies that the public spending is mainly financed through taxes. Besides, institutional quality will be inversely related to corruption. When $\phi = 1$ there is no corruption in the economy, whereas complete corruption will occur when $\phi = 0$. Therefore, the lower ϕ is, the greater will be the leakage of tax revenue. Thus, lower quality (smaller ϕ) implies more costly tax collection and, hence, a less effective tax system.

We assume that there are two policies, monetary and fiscal policy, which are controlled by an independent central bank and the government, respectively. Concretely, the independent central bank chooses inflation and the government chooses the tax rate as instruments, in order to minimise the following loss functions, respectively:

$$L_G = \frac{1}{2}\sum_{t=0}^{T}\theta_G^t\left(\pi_t^2 + \delta_G x_t^2 + \gamma_G\left(g_t - \bar{g}\right)^2\right), \tag{2.4}$$

[3] Expression (2.1) is derived from the optimization problem of a competitive firm using only one input (labour). Output is produced by labour (L), subject to a productivity shock ε_t: $X_t = L^\gamma e^{\varepsilon_t/2}$, where $\varepsilon_t \sim iid(0, \sigma_\varepsilon^2)$. Workers set the nominal wage (w in logs) to achieve a target real wage w^*: $w = w^* + p^e$. Distortionary taxes are levied on production. The representative firm maximizes profit, given by: $PL^\gamma e^{\varepsilon_t/2}(1-\tau) - WL$. Solving for the firm's optimization problem (assuming it can hire the labour it demands at the given nominal wage) and taking logs, yields the output supply: $x_t = \alpha\left(\pi_t - \pi_t^e - \tau_t - w^* + \ln\gamma\right) + \frac{\varepsilon_t}{2(1-\gamma)}$. For simplicity we set $\gamma = 0.5$, so that $\alpha = \frac{\gamma}{(1-\gamma)} = 1$, and, following Alesina and Tabellini (1987), we set $\ln\gamma = 0$ and we suppose that $w^* = 0$, so the expression for output becomes (2.1).

where $\delta_G, \gamma_G > 0$, $0 < \theta_G < 1$ and $\bar{g} \geq 0$, and

$$L_{CB} = \frac{1}{2} \sum_{t=0}^{T} \theta_{CB}^{t} \left(\pi_t^2 + \delta_{CB} x_t^2 + \gamma_{CB} \left(g_t - \bar{g} \right)^2 \right), \tag{2.5}$$

where $\delta_{CB} > 0, \gamma_{CB} \geq 0$ and $0 < \theta_{CB} < 1$.[4]

Let us make some comments:

- We assume that both policymakers wish to minimise the deviations of inflation, output and public spending from some targets. Without loss of generality, the targeted inflation rate is normalised to zero. The target for the output growth rate is also normalised to zero, which is the natural output level reached in the absence of tax distortions and shocks whenever the price level is correctly anticipated by the private sector.

- Although the targets are identical for both authorities as suggested by Dixit and Lambertini (2003), their weights may differ. Alesina and Tabellini (1987) argue that the two policymakers can differ in the weights attributed to output and public spending relative to inflation. As these authors pointed out, an independent central bank is not elected and, in most industrial countries, it enjoys various degrees of independence from the fiscal authority.

- The positiveness of γ_G indicates that the government takes into account public goods provision in addition to stabilising inflation and output.[5] One economic interpretation of this fact is the following: it is well-known that the government is under the influence of several important interest groups in the economy so that it simultaneously aims at stabilising output and inflation, as well as meeting a spending target. As Hefeker (2010) points out, the spending target $\bar{g}$ reflects standard political economy arguments about reelection motives, interest group pressure or simply the absence of alternative instruments to increase political support.

- There does not seem to be an agreement in the literature about the values of the weights in the loss functions. For instance, some authors, like Debelle and Fischer (1994), Berger et al. (2001) and Hefeker (2010), assume that $\gamma_{CB} = 0$. Alesina and Tabellini (1987) assume that $\delta_{CB} < \delta_G$ and $\gamma_{CB} < \gamma_G$. In Huang and Wei (2006), the

[4] The variables θ_G and θ_{CB} represent the discount factors for the government and central bank, respectively.

[5] Other papers that also include the public goods provision in the government's loss functions are Alesina and Tabellini (1987), Beetsma and Bovenberg (1997), Huang and Wei (2006) and Ferre and Manzano (2012), among others.

weights for both authorities are identical, except the weight attributed to inflation. In particular, in their model $\frac{\delta_G}{\gamma_G} = \frac{\delta_{CB}}{\gamma_{CB}}$.[6] The general framework presented in this paper encompasses all the models in this literature.

The timing of events will be as follows. First of all, expectations and thus, wages, are set. Afterwards, the shock ε occurs. Finally, the monetary and fiscal instruments will be chosen. The model is solved by minimising the loss function of the policymakers, holding π^e constant and then imposing rational expectations.

With rational expectations and minimising the government's and central bank's loss functions, inflation and tax are given by

$$\pi_t = \frac{\eta}{\delta_G + \phi^2\gamma_G + k\eta}\bar{g} - \phi\frac{\eta}{\delta_G + \phi^2\gamma_G + (k+\phi)\,\eta}\varepsilon_t \text{ and} \tag{2.6}$$

$$\tau_t = \phi\frac{\gamma_G}{\delta_G + \phi^2\gamma_G + k\eta}\bar{g} + \frac{\delta_G + k\eta}{\delta_G + \phi^2\gamma_G + (k+\phi)\,\eta}\varepsilon_t, \tag{2.7}$$

where $\eta = k\gamma_{CB}\delta_G + \phi\delta_{CB}\gamma_G$.[7] Moreover, it follows that

$$\bar{g} - g_t = \frac{\delta_G}{\eta}\pi_t \text{ and} \tag{2.8}$$

$$x_t = -\frac{\phi\gamma_G}{\eta}\pi_t. \tag{2.9}$$

Therefore, it can be seen that the higher the inflation is, the lower g_t and x_t. In equilibrium, output and public spending are below their targets (0 and $\bar{g}$, respectively). The higher is the need to use distortionary taxation to finance the public spending (i.e. an increase in $\bar{g}$), the further away are inflation, output and public spending from their respective targets.

2.1. Comparative Statics

This section presents some comparative static results obtained from the equilibrium of the model.

2.1.1. Institutional Quality

Using the expressions for inflation and taxes, taking into account expectations and differntiating with respect to the degree of corruption, it can be shown that

[6] Huang and Wei (2006) assume the following loss functions:
$L_G = -\frac{1}{2}\left[\pi_t^2 + \delta_G x_t^2 + \gamma_G\,(g_t - \bar{g})^2\right]$ and $L_{CB} = -\frac{1}{2}\left[S\pi_t^2 + \delta_G x_t^2 + \gamma_G\,(g_t - \bar{g})^2\right]$. Thus, in their model $\delta_{CB} = \frac{\delta_G}{S}$ and $\gamma_{CB} = \frac{\gamma_G}{S}$, where S denotes the weight on the inflation rate placed by the central banker.

[7] The derivations of these expressions are included in the Appendix.

$$\frac{\partial}{\partial\phi}E\left(\tau_t\right) > 0 \leftrightarrow \phi < \bar{\phi}_\tau \text{ and} \tag{2.10}$$

$$\frac{\partial}{\partial\phi}E\left(\pi_t\right) > 0 \longleftrightarrow \phi < \bar{\phi}_\pi, \tag{2.11}$$

where $\bar{\phi}_\tau = \sqrt{\frac{\delta_G}{\gamma_G}(k^2\gamma_{CB}+1)}$ and $\bar{\phi}_\pi = \frac{\delta_G}{\gamma_G}\left(\sqrt{\frac{k^2\gamma_{BC}^2}{\delta_{BC}^2} + \frac{\gamma_G}{\delta_G}} - \frac{k\gamma_{BC}}{\delta_{BC}}\right)$.

From Expression (2.10), it follows that for poor institutional quality $\left(\phi < \bar{\phi}_\tau\right)$, given that the collection through taxes is inefficient, the optimal response to an increase in corruption would be to lower the tax rate. However, for moderate institutional quality $\left(\phi > \bar{\phi}_\tau\right)$, the optimal response to an increase in corruption is to raise the tax rate. From Expression (2.11), we can see that for poor institutional quality $\left(\phi < \bar{\phi}_\pi\right)$, the optimal response to an increase in corruption would be to lower the expected inflation. However, for moderate institutional quality $\left(\phi > \bar{\phi}_\pi\right)$, the optimal response to an increase in corruption is to raise the expected inflation. Moreover, we obtain the following relationship through the thresholds for inflation and taxes in expected terms: $\bar{\phi}_\pi < \bar{\phi}_\tau$. In particular, notice that this relationship indicates that when the expected inflation decreases due to an increase in corruption, the tax rate (in expected terms) also decreases.

Next, we try to intuitively understand the responses of both authorities when there is an increase in corruption ($\nabla\phi$).

From the point of view of the fiscal authority, a decrease in institutional quality has two opposite effects on the expected tax rate: a public spending effect and an output effect.

• *Public spending effect for the fiscal authority:* The government tends to increase taxes in order to compensate the decrease in public spending since institutional quality is poorer.[8]

• *Output effect for the fiscal authority:* The government tends to lower taxes in order to raise output and be closer to its target.

Which of the two previous effects dominates will depend on parameter values. In particular, notice that if the government is more worried about getting the output target than the public spending target ($\delta_G > \gamma_G$), the second effect dominates and hence, the expected tax rate decreases with a reduction in institutional quality or, in other words, $\frac{\partial}{\partial\phi}E\left(\tau_t\right) > 0$.[9]

On the other hand, from the point of view of the central bank, a decrease in institutional quality has two effects on the expected inflation: a public spending effect and an output effect.

• *Public spending effect for the monetary authority:* The central bank has more incentives to inflate in order to raise public spending and be closer to its target.

[8] A decrease in ϕ yields a reduction in $\phi E\left(\tau_t\right)$.

[9] Notice that when $\delta_G \geq \gamma_G$, $\bar{\phi}_\tau > 1$ and, consequently, $\bar{\phi}_\tau > 0$ whenever $\phi \in [0, 1]$.

• *Output effect for the monetary authority:* The central bank can have two different responses depending on the change in the expected tax rate. On the one hand, if the government reduces taxes because of the decrease in ϕ, then the central bank has less incentives to inflate. On the other hand, if the government raises taxes, then the central bank has more incentives to inflate in order to raise output and be closer to its target.

Notice that when the tax rate decreases in ϕ (a reduction in ϕ induces an increase in $E(\tau_t)$), then the previous two effects move in the same direction, so the central bank has more incentives to inflate. Consequently, in this case we could conclude that the expected inflation decreases in ϕ. By contrast, when the taxes increase in ϕ (a reduction in ϕ induces a decrease in $E(\tau_t)$), then the previous two effects work in opposite ways. When the output effect dominates, the expected inflation will increase in ϕ.

The following figure illustrates the results obtained previously:

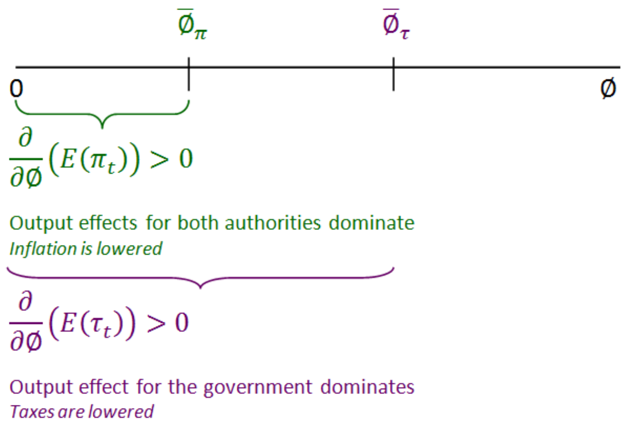

Figure 1. Representation of comparative statics

2.1.2. Seigniorage

Next, we now look at the effects on the government's revenues through money creation. Using the expressions of inflation and taxes given in (2.6) and (2.7), respectively, we obtain

$$\frac{\partial}{\partial k} E(\tau_t) < 0 \text{ and}$$

$$\frac{\partial}{\partial k} E(\pi_t) < 0 \text{ if and only if } k > k_1,$$

where $k_1 = \frac{\sqrt{\delta_G \gamma_{CB}(\delta_G + \phi^2 \gamma_G)} - \phi \gamma_G \delta_{CB}}{\delta_G \gamma_{CB}}$.

To understand these results notice that if the ability to raise revenue through inflation increases, then the total revenue increases ($\frac{\partial}{\partial k} E(k\pi_t) > 0$). This implies that the fiscal authority has less incentives to increase taxes ($\frac{\partial}{\partial k} E(\tau_t) < 0$). In turn, this has two effects on the behaviour of the central bank: on the one hand, taking into account the objective of output, the reduction in taxes decreases the incentives to inflate; on the other hand, given the objective of public spending, the reduction in taxes increases the incentives to inflate. Whenever $\frac{\delta_{CB}}{\gamma_{CB}}$ is high enough,[10] the first effect dominates and, therefore, the overall effect is that the central bank has less incentives to inflate, and therefore, $\frac{\partial}{\partial k}E(\pi_t) < 0$. However, when $\frac{\delta_{CB}}{\gamma_{CB}}$ is low enough, the opposite could be true.

3. Central Bank Conservativeness with Corruption

In this section, we first introduce a measure of the relative conservativeness of the central bank with respect to the government. Then, we address the issue of what design of monetary institution maximises social welfare.

3.1. Conservativeness Indicator

The term conservativeness refers to the degree of central bank's inflation aversion. In the literature, there are different ways to measure conservativeness. Rogoff (1985) and Beetsma and Bovenberg (1997) define a "conservative" central banker as one that would care relatively more about inflation and less about output than society. For Alesina and Tabellini (1987), the central bank is conservative when $\delta_{CB} < \delta_G$ and $\gamma_{CB} < \gamma_G$ in Expressions (2.4) and (2.5). Berger et al. (2001) and Huang and Wei (2006) consider that the central banker is more averse to inflation than the government when (s)he places a greater weight on price stability than does the government, whereas the remainder weights coincide for both authorities. Huang and Wei (2006) can measure the degree of conservativeness of the central banker by the excess weight he or she places on the inflation term relative to the government.

Next, we will introduce a new measure of the conservativeness of the central bank in the presence of corruption, which will fit with all the notions of conservativeness previously mentioned.

Definition 1. *The relative degree of conservativeness of the central bank with respect to the conservativeness of the government (c) is defined as:*

$$c = \frac{k + \phi}{\phi \frac{\delta_{CB}}{\delta_G} + k \frac{\gamma_{CB}}{\gamma_G}}. \tag{3.1}$$

Remark: *Note that this indicator is the weighted harmonic mean of the relative weights of the central bank with respect to the weights of the government in their loss functions.*

[10] Note that in this case $k_1 < 0$ and, therefore, $k > k_1$.

To understand our indicator, let us consider some particular cases:

1) When both authorities have the same preferences, $\delta_{CB} = \delta_G$ and $\gamma_{CB} = \gamma_G$, then $c = 1$. Thus, in this case the two authorities have the same degree of conservativeness, i.e., the central bank is as conservative as the government.

2) If $\delta_{CB} \leq \delta_G$ and $\gamma_{CB} \leq \gamma_G$ and at least one of the previous inequalities is strict, then the central bank is more conservative than the government in the Alesina and Tabellini's sense. In this case, $c > 1$, i.e., the central bank is more conservative than the government.

3) If $\gamma_{CB} = \gamma_G$, then $c > 1$ is equivalent to $\delta_{CB} < \delta_G$, and in this case, the indicator of conservativeness we consider and the one proposed by Rogoff coincide.

4) If $\delta_{CB} = \frac{\delta_G}{S}$ and $\gamma_{CB} = \frac{\gamma_G}{S}$ (as in Huang and Wei's model, 2006),[11] then $c = S$. Huang and Wei (2006) propose as a measure of conservativeness $S-1$. Thus, both indicators are equivalent.

5) If $\phi = 1$ and $k = 1$, i.e., there is not any degree of corruption and the degree of seigniorage is complete, then we obtain the same indicator as in Ferre and Manzano (2012).

6) If $\phi = 0$, i.e., there is complete corruption, then $c = \frac{\gamma_G}{\gamma_{CB}}$. In this case, note that the output weights are irrelevant for our conservativeness measure. The reason for this fact is that when $\phi = 0$, the government chooses the tax rate such that output is nul. As the fiscal authority cannot collect resources through taxes, conservativeness will be determined by the public spending weights, as this will determine whether inflation will be high or low. In this way, if the public spending weight of the government is relatively high, it will favour high inflation, forcing the central bank to be more conservative. On the other hand, if the public spending weight of the central bank is high, the central bank will be less conservative.

Proposition 2. *Delegation of monetary policy to an independent and "conservative enough" authority (c >1) reduces the expected inflation and the variance of inflation, but increases the expected value and the variance of deviations of output and public spending from its targets.*

The results derived in Proposition 2 are in line with the related literature see (Rogoff, 1985; Debelle and Fischer, 1994; among others). In addition, this proposition shows that the proposed measure of conservativeness of the central bank is effective.

3.2. Welfare Analysis under Corruption

In this subsection we will study how conservative should an independent central bank be, from the society's welfare point of view, when there are two different instruments and policies

[11] See Footnote 2.

and there is corruption.

In order to study the optimal degree of conservativeness of the central bank, following Debelle and Fischer (1994),[12] we will consider a general loss function for the society:

$$L_S = \frac{1}{2} \sum_{t=0}^{T} \theta_S^t \left(\pi_t^2 + \delta_S x_t^2 + \gamma_S \left(g_t - \bar{g} \right)^2 \right), \tag{3.2}$$

where $0 < \theta_S < 1$, $\delta_S > 0$ and $\gamma_S \geq 0$.

The problem consists in finding δ_{CB} and γ_{CB} that minimise the society's loss. Therefore, we have

$$\min_{\delta_{CB}, \gamma_{CB}} E\left[L_S \right].$$

In the Appendix it is shown that

$$E\left[L_S\right] = \Omega \left(\left(\frac{1}{D_1(c)} \bar{g} \right)^2 + \left(\frac{\phi}{D_2(c)} \right)^2 \sigma_\varepsilon^2 \right) \left(1 + \delta_S \left(\frac{\phi c}{\delta_G (k+\phi)} \right)^2 + \gamma_S \left(\frac{c}{\gamma_G (k+\phi)} \right)^2 \right), \tag{3.3}$$

where $\Omega = (k+\phi)^2 \gamma_G^2 \delta_G^2 \frac{\left(1-\theta_S^{T+1}\right)}{2(1-\theta_S)}$, with

$$\begin{aligned} D_1(c) &= c\left(\delta_G + \phi^2 \gamma_G\right) + k \gamma_G \delta_G (k+\phi) \text{ and} \\ D_2(c) &= c\left(\delta_G + \phi^2 \gamma_G\right) + \gamma_G \delta_G (k+\phi)^2 . \end{aligned}$$

This expression indicates that the parameters δ_{CB} and γ_{CB} affect the society's welfare through c. Therefore, the problem of finding the optimal relative weights, i.e., δ_{CB} and γ_{CB}, that maximise the society's welfare is reduced to obtaining the optimal relative degree of conservativeness of the central bank. Formally,

$$\min_c E\left[L_S\right]. \tag{3.4}$$

Proposition 3. *There exists a unique value of c, denoted by c^*, that maximises society's welfare. When $\phi > 0$, $c^* \in \left(\beta, \frac{k+\phi}{k} \beta \right)$ where $\beta = \frac{\gamma_G \delta_G \left(\delta_G + \phi^2 \gamma_G\right)}{\delta_G^2 \gamma_S + \phi^2 \gamma_G^2 \delta_S}$ and, when $\phi = 0$, $c^* = \frac{\gamma_G}{\gamma_S}$.*

Remark: *The extremes of the interval stated in Proposition 3 are achieved when σ_ε^2 takes an extreme value. Concretely, when $\sigma_\varepsilon^2 = 0$, then $c^* = \frac{k+\phi}{k}\beta$ and when $\sigma_\varepsilon^2 \to \infty$, then $c^* = \beta$.*

Proposition 3 indicates that when there is complete corruption ($\phi = 0$) and if society's spending weight is higher (lower) than the government's, the central bank should be less

[12] Debelle and Fischer (1994), in a model similar to Alesina and Tabellini's, analyze how conservative should a central bank be. They show that the optimal degree of conservatism of the central bank depends on the society's aversion to inflation and output fluctuations.

(more) conservative. As $c = \frac{\gamma_G}{\gamma_{CB}}$, then in the optimal $\gamma_{CB} = \gamma_S$ since $c^* = \frac{\gamma_G}{\gamma_S}$. Moreover, when there are no political distortions, that is, when the government's and society's preferences coincide, Proposition 3 implies that in this case $c^* = 1$, i.e., the central bank has to be as conservative as the government.

In what follows we focus on $\phi > 0$ and we assume that there are no political distortions or, in other words, the government is benevolent. This is due to the fact that the government is choosen through the society, then it is natural to consider that the preferences of them are similar. In the following corollary, we study how the optimal degree varies with some parameter values.

Corollary 4. *Suppose that the government is benevolent, then the optimal relative degree of conservativeness of the central bank satisfies that* $c^* \in \left(1, \frac{k+\phi}{k}\right)$. *Moreover, the following comparative static results are derived:*

a) c^* *is decreasing in* σ_ε^2,

b) c^* *is increasing in* $\bar{g}$,

c) c^* *is decreasing in* k, *and*

d) c^* *is increasing in* ϕ *whenever* σ_ε^2 *is low enough. The opposite result may arise when* σ_ε^2 *is high enough.*

Corollary 4a can be interpreted as follows. When the volatility of supply shocks (σ_ε^2) increases, the variances of inflation and of the deviations of output and public spending increase. To compensate the effect on the variance of the inflation, the central bank should be more conservative. By contrast, taking into account the effect on the variances of output and public spending deviations, the central bank should be less conservative. In equilibrium, this last effect dominates and, thus, we obtain that the higher the volatility of supply shocks, the less conservative should the central bank be.

The intuition behind Corollary 4b is that the higher the target for public spending ($\bar{g}$), the higher the expected inflation and, thus, more conservative the central bank would have to be.

The reason behind Corollary 4c has to do with the fact that, if seigniorage (k) decreases, the expected deviations of output and public spending increase. To compensate for this effect, the central bank should be more conservative.

According to Corollary 4d, when the shocks are not significant and there is more corruption ($\nabla\phi$), the central bank should be less conservative. Intuitively, if the institutional quality is poorer, the expected deviation of public spending increases. To offset this effect, the central bank should be less conservative. However, the opposite result may arise when σ_ε^2 is high enough. Notice that the higher the volatility of shocks, the higher the variances of inflation and of the deviations of output and public spending are. To compensate for this effect, the central bank should be more conservative.

Next, we are interested, from a normative point of view, in finding the optimal relative weights of the central bank's preferences. By solving the optimisation problem stated in (3.4), we are finding a relationship that the optimal values of δ_{CB} and γ_{CB} must satisfy. Therefore, without any loss of generality, as the relevant variable in the optimisation problem of society's welfare is c, we can interpret that we have a degree of freedom when choosing the optimal values δ_{CB} and γ_{CB}. Consequently, we can suppose that $\gamma_{CB} = 0$. In this case, the following corollary applies:

Corollary 5. *If there are no political distortions and public spending is not included in the preferences of the central bank* ($\gamma_{CB} = 0$),[13] *the optimal relative weight of output satisfies* $\delta^*_{CB} \in \left(\frac{k}{\phi}\delta_G, \frac{k+\phi}{\phi}\delta_G\right)$.

In this case, whenever $k > \phi$, the central bank would be less conservative than the government and society in the Rogoff sense. However, we cannot conclude that the central bank should be less conservative in this case, since $c^* > 1$ as shown Corollary 4. From a normative point of view, we could then justify that public spending does not need to be included in the loss function of the monetary authority, but the consequence of this is that the socially optimal value of δ_{CB} has to be higher than $\frac{k}{\phi}\delta_G$.

Corollary 6. *When the preferences of the government and society coincide and* $\sigma^2_\varepsilon = 0$, *then* $c^* = \frac{k+\phi}{k}$.

Corollary 6 provides a generalisation of Huang and Wei's results (2006). These authors show that $S^* = 1 + \phi$. Using this optimal value and taking into account that in their model $\delta_{CB} = \frac{\delta_G}{S}$ and $\gamma_{CB} = \frac{\gamma_G}{S}$ (see Footnote 2), the optimal values obtained by these authors result in a degree of relative conservativeness equal to $1+\phi$, which coincides with the one derived in Corollary 6 (since in their model $k = 1$). Therefore, this analysis shows the robustness of the results derived by Huang and Wei (2006). However, it is important to point out that there are other alternative values that achieve the same degree of conservativeness and, therefore, our result is more general. For instance, we could consider the case where $\gamma^*_{CB} = 0$ and $\delta^*_{CB} = \frac{k}{\phi}\delta_G$. Further, one could argue that the empirical value of k is strictly smaller than 1.[14]

[13] Like Debelle and Fischer (1994) and Berger et al. (2001).

[14] Gros (2004) puts forward a methodology to assess the fiscal implications for the new EU members from central and eastern Europe of joing the euro area. He shows that the rules of the European Central Bank on the distribution of seigniorage favour poorer countries.

4. Conclusions

In this article, we extended Alesina and Tabellini's model (1987) allowing for corruption by considering that there is a connection between the government's fiscal capacity and the quality of institutions. There are two policies, monetary and fiscal, which are controlled by an independent central bank and the government, respectively. The independent monetary authority or central bank controls inflation and the government chooses taxes. We then proceed to carry out a welfare analysis by introducing a measure of the degree of conservativeness of the central bank with respect to the government and, then, characterising its optimal social value.

We show that, from a normative perspective, one can design a central bank that cares about public spending, besides output and inflation. A central bank could equally not care about public spending, but then the optimal weight on output stabilisation would have to be higher. In other words, from a Rogoff's perspective, it could be "less conservative". Moreover, we show that when the preferences of the government and society coincide, then the central bank should be more conservative than the government (and the society), except in the case of complete corruption. In this last case, we obtain that both policymakers would have to be equally conservative.

In addition, we develop some comparative static results. In particular, we study how an increase in the degree of corruption affects the optimal relative degree of conservativeness of the central bank. We find that if the shocks that affect the economy are not very relevant, this optimal value decreases in the level of corruption. In other words, a central bank has to be less conservative in economies with weak institutions. However, this result may reverse when the shocks are significant as in crisis times.

Appendix

Proof of (2.6) and (2.7). If we substitute (2.1), (2.2) and (2.3) into (2.4) and (2.5), we obtain

$$L_G = \frac{1}{2}\sum_{t=0}^{T}\theta_G^t\left(\pi_t^2 + \delta_G\left(\pi_t - \pi^e - \tau_t + \varepsilon_t\right)^2 + \gamma_G\left(\phi\tau_t + k\pi_t - \bar{g}\right)^2\right) \text{ and}$$

$$L_{CB} = \frac{1}{2}\sum_{t=0}^{T}\theta_{CB}^t\left(\pi_t^2 + \delta_{CB}\left(\pi_t - \pi^e - \tau_t + \varepsilon_t\right)^2 + \gamma_{CB}\left(\phi\tau_t + k\pi_t - \bar{g}\right)^2\right).$$

The first-order condition of the government's optimisation problem is given by

$$\frac{\partial L_G}{\partial \tau_t} = \theta_G^t\left[-\delta_G\left(\pi_t - \pi^e - \tau_t + \varepsilon_t\right) + \phi\gamma_G\left(\phi\tau_t + k\pi_t - \bar{g}\right)\right] = 0,$$

and hence,

$$\tau_t = \frac{\left(\delta_G - \phi\gamma_G k\right)\pi_t - \delta_G\left(\pi^e - \varepsilon_t\right) + \phi\gamma_G\bar{g}}{\delta_G + \phi^2\gamma_G}. \tag{4.1}$$

For the central bank, the first-order condition implies that

$$\frac{\partial L_{CB}}{\partial \pi_t} = \theta_{CB}^t\left[\pi_t + \delta_{CB}\left(\pi_t - \pi^e - \tau_t + \varepsilon_t\right) + k\gamma_{CB}\left(\phi\tau_t + k\pi_t - \bar{g}\right)\right] = 0,$$

or equivalently,

$$\pi_t = \frac{\delta_{CB}\left(\pi^e + \tau_t - \varepsilon_t\right) - k\gamma_{CB}\left(\phi\tau_t - \bar{g}\right)}{1 + \delta_{CB} + k^2\gamma_{CB}}. \tag{4.2}$$

Plugging (4.1) into (4.2), it follows that

$$\pi_t = \frac{\left(\bar{g} + \phi\left(\pi^e - \varepsilon_t\right)\right)\eta}{\delta_G + \phi^2\gamma_G + \left(k + \phi\right)\eta}, \tag{4.3}$$

where $\eta = k\gamma_{CB}\delta_G + \phi\delta_{CB}\gamma_G$. Taking expectations in the previous equality and solving for π^e, we get

$$\pi^e = \frac{\eta}{\delta_G + \phi^2\gamma_G + k\eta}\bar{g}. \tag{4.4}$$

Substituting the expression of π^e given in (4.4) into (4.3), we have

$$\pi_t = \frac{\eta}{\delta_G + \phi^2\gamma_G + k\eta}\bar{g} - \phi\frac{\eta}{\delta_G + \phi^2\gamma_G + \left(k + \phi\right)\eta}\varepsilon_t. \tag{4.5}$$

Using (4.4) and (4.5) in (4.1), and after some algebra, we obtain

$$\tau_t = \phi\frac{\gamma_G}{\delta_G + \phi^2\gamma_G + k\eta}\bar{g} + \frac{\delta_G + k\eta}{\delta_G + \phi^2\gamma_G + \left(k + \phi\right)\eta}\varepsilon_t. \blacksquare$$

Proof of (2.8) and (2.9). The first-order conditions of the government's optimisation problem can be rewritten as

$$x_t = -\frac{\phi\gamma_G}{\delta_G}\left(\bar{g} - g_t\right). \tag{4.6}$$

Analogously, for the central bank, we have

$$\pi_t + \delta_{CB} x_t + k\gamma_{CB}\left(g_t - \bar{g}\right) = 0.$$

Using the expression (4.6), it follows that

$$\bar{g} - g_t = \frac{\delta_G}{\eta}\pi_t. \tag{4.7}$$

Hence,

$$x_t = -\frac{\phi\gamma_G}{\eta}\pi_t. \blacksquare \tag{4.8}$$

Proof of (3.3). Substituting (2.8) and (2.9) into (3.2), we get

$$L_S = \frac{1}{2}\sum_{t=0}^{T}\theta_S^t\left(\pi_t^2 + \delta_S\left(\frac{\phi\gamma_G}{\eta}\pi_t\right)^2 + \gamma_S\left(\frac{\delta_G}{\eta}\pi_t\right)^2\right),$$

or equivalently,

$$L_S = \frac{1}{2}\sum_{t=0}^{T}\theta_S^t\pi_t^2\left(1 + \delta_S\left(\frac{\phi c}{\delta_G\left(k+\phi\right)}\right)^2 + \gamma_S\left(\frac{c}{\gamma_G\left(k+\phi\right)}\right)^2\right),$$

since

$$\eta = \frac{\gamma_G\delta_G\left(k+\phi\right)}{c}. \tag{4.9}$$

Taking expectations, we get

$$E\left[L_S\right] = \frac{1}{2}\sum_{t=0}^{T}\theta_S^t E\left(\pi_t^2\right)\left(1 + \delta_S\left(\frac{\phi c}{\delta_G\left(k+\phi\right)}\right)^2 + \gamma_S\left(\frac{c}{\gamma_G\left(k+\phi\right)}\right)^2\right).$$

Moreover, using (4.9) in (2.6), we obtain

$$\pi_t = \frac{\gamma_G\delta_G\left(k+\phi\right)}{D_1(c)}\bar{g} - \frac{\phi\gamma_G\delta_G\left(k+\phi\right)}{D_2(c)}\varepsilon_t,$$

where

$$\begin{aligned} D_1(c) &= c\left(\delta_G + \phi^2\gamma_G\right) + k\gamma_G\delta_G\left(k+\phi\right) \text{ and} \\ D_2(c) &= c\left(\delta_G + \phi^2\gamma_G\right) + \gamma_G\delta_G\left(k+\phi\right)^2. \end{aligned}$$

Hence,

$$E\left(\pi_t^2\right) = \left(E\left(\pi_t\right)\right)^2 + var\left(\pi_t\right) = \left(\frac{\gamma_G\delta_G\left(k+\phi\right)}{D_1(c)}\bar{g}\right)^2 + \left(\frac{\phi\gamma_G\delta_G\left(k+\phi\right)}{D_2(c)}\right)^2\sigma_\varepsilon^2.$$

Using this expression in the last formula for $E\left[L_S\right]$, direct computations yield

$$E\left[L_S\right] = \Omega\left(\left(\frac{1}{D_1(c)}\bar{g}\right)^2 + \left(\frac{\phi}{D_2(c)}\right)^2\sigma_\varepsilon^2\right)\left(1 + \delta_S\left(\frac{\phi c}{\delta_G\left(k+\phi\right)}\right)^2 + \gamma_S\left(\frac{c}{\gamma_G\left(k+\phi\right)}\right)^2\right),$$

where $\Omega = (k+\phi)^2 \gamma_G^2 \delta_G^2 \frac{\left(1-\theta_S^{T+1}\right)}{2(1-\theta_S)}$. ■

Proof of Propostion 2. Recall that $E(\pi_t) = \frac{\gamma_G \delta_G (k+\phi)}{c\left(\delta_G+\phi^2\gamma_G\right)+k\gamma_G\delta_G(k+\phi)}\bar{g}$ and $var\,(\pi_t) = \left(\frac{\phi\gamma_G\delta_G(k+\phi)}{c\left(\delta_G+\phi^2\gamma_G\right)+\gamma_G\delta_G(k+\phi)^2}\right)^2 \sigma_\varepsilon^2$. Moreover, taking into account these expressions, (4.7), (4.8) and (4.9), it follows that

$$E\left(0-x_t\right) = \frac{c\phi\gamma_G}{c\left(\delta_G+\phi^2\gamma_G\right)+k\gamma_G\delta_G\left(k+\phi\right)}\bar{g},$$

$$var\left(0-x_t\right) = \frac{c^2\phi^4\gamma_G^2}{\left(c\left(\delta_G+\phi^2\gamma_G\right)+\gamma_G\delta_G\left(k+\phi\right)^2\right)^2}\sigma_\varepsilon^2,$$

$$E\left(\bar{g}-g_t\right) = \frac{c\delta_G}{c\left(\delta_G+\phi^2\gamma_G\right)+k\gamma_G\delta_G\left(k+\phi\right)}\bar{g} \text{ and}$$

$$var\left(\bar{g}-g_t\right) = \frac{c^2\phi^2\delta_G^2}{\left(c\left(\delta_G+\phi^2\gamma_G\right)+\gamma_G\delta_G\left(k+\phi\right)^2\right)^2}\sigma_\varepsilon^2.$$

Differentiating these expressions, we have that $\frac{\partial}{\partial c}E(\pi_t) < 0$, $\frac{\partial}{\partial c}var(\pi_t) < 0$, $\frac{\partial}{\partial c}E\left(0-x_t\right) > 0$, $\frac{\partial}{\partial c}E\left(\bar{g}-g_t\right) > 0$, $\frac{\partial}{\partial c}var\left(0-x_t\right) > 0$ and $\frac{\partial}{\partial c}var\left(\bar{g}-g_t\right) > 0$. ■

Proof of Proposition 3. Let's minimise the expected value of the loss function for society

$$\min_c E\left[L_S\right].$$

The first-order condition of this optimisation problem is given by

$$\frac{\partial E\left[L_S\right]}{\partial c} = \frac{2\Omega\left(\delta_S\phi^2\gamma_G^2+\gamma_S\delta_G^2\right)}{\gamma_G\delta_G\left(k+\phi\right)}\left(\frac{kc-\left(k+\phi\right)\beta}{\left(D_1(c)\right)^3}\bar{g}^2+\phi^2\left(k+\phi\right)\frac{c-\beta}{\left(D_2(c)\right)^3}\sigma_\varepsilon^2\right) = 0, \quad (4.10)$$

where

$$\beta = \frac{\delta_G\gamma_G\left(\delta_G+\phi^2\gamma_G\right)}{\delta_G^2\gamma_S+\phi^2\gamma_G^2\delta_S}.$$

Thus, we can distinguish two cases:

Case A: $\phi = 0$. In this case, from (4.10) we get that $c^* = \beta = \frac{\gamma_G}{\gamma_S}$.

Case B: $\phi > 0$. Note that if $c > \frac{(k+\phi)}{k}\beta$, then $\frac{\partial}{\partial c}E\left[L_S\right] > 0$. Otherwise, if $c < \beta$, then $\frac{\partial}{\partial c}E\left[L_S\right] < 0$. Hence, we know that there exists a value of c belonging to the interval $\left(\beta, \frac{(k+\phi)}{k}\beta\right)$ that satisfies the first order condition.

In relation to the second-order condition note that

$$\frac{\partial^2 E\left[L_S\right]}{\partial^2 c} = -\frac{2\Omega\left(\delta_S\phi^2\gamma_G^2+\gamma_S\delta_G^2\right)}{\gamma_G\delta_G\left(k+\phi\right)}\left(\frac{\left(\delta_G+\phi^2\gamma_G\right)\left(2ck-3\beta\left(k+\phi\right)\right)-\delta_G\gamma_G k^2\left(k+\phi\right)}{\left(D_1(c)\right)^4}\bar{g}^2+\right.$$
$$\left.+\left(k+\phi\right)\phi^2\frac{\left(\delta_G+\phi^2\gamma_G\right)\left(2c-3\beta\right)-\delta_G\gamma_G\left(k+\phi\right)^2}{\left(D_2(c)\right)^4}\sigma_\varepsilon^2\right).$$

In a value of c that satisfies the first-order condition, it holds that

$$\bar{g}^2 = -\phi^2 (k+\phi) \frac{(c-\beta)(D_1(c))^3}{(kc-(k+\phi)\beta)(D_2(c))^3}\sigma_\varepsilon^2. \tag{4.11}$$

Using (4.11) in the expression of $\frac{\partial^2 E[L_S]}{\partial^2 c}$, we get

$$\frac{\partial^2 E[L_S]}{\partial^2 c} = \frac{2\Omega\phi^3\left(\delta_S\phi^2\gamma_G^2+\gamma_S\delta_G^2\right)p(c)}{\gamma_G\delta_G(D_2(c))^4(D_1(c))(-kc+(k+\phi)\beta)}\sigma_\varepsilon^2,$$

where $p(c) = p_2c^2 + p_1c + p_0$, with

$$\begin{aligned}
p_2 &= \left(\delta_G+\phi^2\gamma_G\right)\left(\beta\left(\delta_G+\phi^2\gamma_G\right)-3k\gamma_G\delta_G(k+\phi)\right),\\
p_1 &= 4\beta\gamma_G\delta_G(2k+\phi)(k+\phi)\left(\delta_G+\phi^2\gamma_G\right) \text{ and}\\
p_0 &= \beta\gamma_G\delta_G(k+\phi)^2\left(-3\beta\left(\delta_G+\phi^2\gamma_G\right)+k\gamma_G\delta_G(k+\phi)\right).
\end{aligned}$$

Now, we distinguish two cases:

Case 1: If $\left(\beta\left(\delta_G+\phi^2\gamma_G\right)-3k\gamma_G\delta_G(k+\phi)\right) < 0$, then we conclude that $p(c)$ has a root strictly higher than $\frac{(k+\phi)}{k}\beta$ and another root strictly smaller than β since $p(\beta) > 0$ and $p(\frac{k+\phi}{k}\beta) > 0$.

Case 2: If $\left(\beta\left(\delta_G+\phi^2\gamma_G\right)-3k\gamma_G\delta_G(k+\phi)\right) \geq 0$, then $p(c)$ is increasing in the interval $\left(\beta, \frac{k+\phi}{k}\beta\right)$. Moreover, in this case it also holds $p(\beta) > 0$.

Therefore, in both cases we conclude that $p(c) > 0$ whenever $c \in \left(\beta, \frac{k+\phi}{k}\beta\right)$. Consequently, it follows that in a value of c that satisfies the first order condition, $\frac{\partial^2}{\partial^2 c}E[L_S] > 0$. This guarantees that the value c that solves the first order condition is unique and it is a minimum. ■

Proof of Corollary 4. a) When the preferences of the government and society coincide $\beta = 1$. In this case, from the first-order condition, we know that c^* satisfies

$$F(c^*, \sigma_\varepsilon^2) = 0,$$

where

$$F(c, \sigma_\varepsilon^2) = \left(\frac{kc-(k+\phi)}{(D_1(c))^3}\bar{g}^2 + \phi^2(k+\phi)\frac{c-1}{(D_2(c))^3}\sigma_\varepsilon^2\right).$$

In addition, from the second-order condition, it follows that $\frac{\partial F}{\partial c}(c^*, \sigma_\varepsilon^2) > 0$. Applying the Implicit Function Theorem, we get

$$\operatorname{sign}\left(\frac{\partial c^*}{\partial \sigma_\varepsilon^2}\right) = -\operatorname{sign}\left(\frac{\partial F}{\partial \sigma_\varepsilon^2}(c^*, \sigma_\varepsilon^2)\right).$$

Moreover, notice that

$$\frac{\partial F}{\partial \sigma_\varepsilon^2}(c^*, \sigma_\varepsilon^2) = \phi^2(k+\phi)\frac{c^*-1}{(D_2(c^*))^3}.$$

As $c^* > 1$, we can conclude that $\frac{\partial F}{\partial \sigma_\varepsilon^2}(c^*, \sigma_\varepsilon^2) > 0$, and hence, $\frac{\partial c^*}{\partial \sigma_\varepsilon^2} < 0$.

b) In this case, from the first-order condition, we know that c^* satisfies

$$F(c^*, \bar{g}) = 0,$$

where

$$F(c, \bar{g}) = \frac{kc - (k+\phi)}{(D_1(c))^3}\bar{g}^2 + \phi^2 (k+\phi) \frac{c-1}{(D_2(c))^3}\sigma_\varepsilon^2.$$

Besides, from the second-order condition, it follows that $\frac{\partial F}{\partial c}(c^*, \bar{g}) > 0$. Combining this result and the Implicit Function Theorem, we get

$$\text{sign}\left(\frac{\partial c^*}{\partial \bar{g}}\right) = -\text{sign}\left(\frac{\partial F}{\partial \bar{g}}(c^*, \bar{g})\right).$$

In addition, after some algebra, it follows that

$$\frac{\partial F}{\partial \bar{g}}(c^*, \bar{g}) = 2\frac{kc^* - (k+\phi)}{(D_1(c^*))^3}\bar{g},$$

As $1 < c^* < \frac{k+\phi}{k}$, it follows that $\frac{\partial F}{\partial \bar{g}}(c^*, \bar{g}) < 0$. This allows us to conclude that $\frac{\partial c^*}{\partial \bar{g}} > 0$.

c) Note that, from the first-order condition, we know that c^* satisfies

$$F(c^*, k) = 0,$$

where

$$F(c, k) = \left(\frac{kc - (k+\phi)}{(D_1(c))^3}\bar{g}^2 + \phi^2 (k+\phi) \frac{c-1}{(D_2(c))^3}\sigma_\varepsilon^2\right).$$

In addition, from the second-order condition, it follows that $\frac{\partial F}{\partial c}(c^*, k) > 0$. Applying the Implicit Function Theorem, we get

$$\text{sign}\left(\frac{\partial c^*}{\partial k}\right) = -\text{sign}\left(\frac{\partial F}{\partial k}(c^*, k)\right).$$

Furthermore, after some algebra, it follows that

$$\begin{aligned}\frac{\partial F}{\partial k}(c, k) &= \left(\frac{\left(\delta_G + \phi^2\gamma_G\right)c^2 - \left(\delta_G + \phi^2\gamma_G + k\gamma_G\delta_G\left(5k + 2\phi\right)\right)c + \delta_G\gamma_G\left(k+\phi\right)\left(5k + 3\phi\right)}{(D_1(c))^4}\bar{g}^2 + \right.\\ &\left.(c-1)\,\phi^2\frac{\left(\delta_G + \phi^2\gamma_G\right)c - 5\delta_G\gamma_G\left(k+\phi\right)^2}{(D_2(c))^4}\sigma_\varepsilon^2\right),\end{aligned}$$

and from (4.11), $\sigma_\varepsilon^2 = -\frac{(ck-(k+\phi))(D_2(c))^3}{\phi^2(k+\phi)(c-1)(D_1(c))^3}\bar{g}^2$. Substituting this formula in the previous equality and operating

$$\frac{\partial F}{\partial k}(c^*, k) = \frac{\phi\left(\delta_G + \phi^2\gamma_G\right)^2 q\left(\frac{\gamma_G\delta_G}{\delta_G + \phi^2\gamma_G}\right)}{(D_1(c^*))^4\left(D_2(c^*)\right)(k+\phi)}\bar{g}^2,$$

where

$$q(z) = (k+\phi)^3 (3k + 3\phi - 2c^* k) z^2 + (k+\phi)(-3(k+\phi)c^* + (5k+\phi)) c^* z + c^{*3}.$$

Next, we distinguish two cases: $k \geq \phi$ and $k < \phi$.

Case 1: $k \geq \phi$. In this case, $1 \geq \frac{3k+3\phi}{5k+\phi}$. Using the expression of $q(z)$, for all $c \geq 1 \geq \frac{3k+3\phi}{5k+\phi}$ $q(z) > 0$ whenever $z > 0$, which implies that $\frac{\partial F}{\partial k}(c^*) > 0$.

Case 2: $k < \phi$. In this case, $1 < \frac{3k+3\phi}{5k+\phi} < \frac{k+\phi}{k}$. First, doing a similar reasoning as in Case 1, we conclude that $\frac{\partial F}{\partial k}(c^*) > 0$ whenever $c \geq \frac{3k+3\phi}{5k+\phi}$. Now, suppose that $1 \leq c < \frac{3k+3\phi}{5k+\phi}$. From direct compuations, the minimum of $q(z)$ is $\overline{z} = \frac{-c(k+\phi)(-3(k+\phi)+c(5k+\phi))}{2(k+\phi)^3(3k+3\phi-2ck)}$ and $q(\overline{z}) > 0$, as $k < \phi$ and $1 \leq c < \frac{3k+3\phi}{5k+\phi}$. Consequently, in this case it is also true that $q(z) > 0$ whenever $z > 0$ and, hence, $\frac{\partial F}{\partial k}(c^*, k) > 0$.

d) Finally, we rewritte the first-order condition as follows:

$$F(c^*, \phi) = 0,$$

where

$$F(c,\phi) = \left(\frac{kc - (k+\phi)}{(D_1(c))^3} \bar{g}^2 + \phi^2 (k+\phi) \frac{c-1}{(D_2(c))^3} \sigma_\varepsilon^2 \right).$$

Besides, from the second-order condition, it follows that $\frac{\partial F}{\partial c}(c^*, \phi) > 0$. Applying the Implicit Function Theorem, we get

$$\text{sign}\left(\frac{\partial c^*}{\partial \phi}\right) = -\text{sign}\left(\frac{\partial F}{\partial \phi}(c^*, \phi)\right).$$

Moreover, after some algebra, it follows that

$$\begin{aligned} \frac{\partial F}{\partial \phi}(c,\phi) \quad = \quad & \Bigg(-\frac{6k\phi\gamma_G c^2 + \left(\delta_G - \phi\gamma_G(5\phi+6k) + 3\gamma_G\delta_G k^2\right)c - 2k\gamma_G\delta_G(\phi+k)}{(D_1(c))^4}\bar{g}^2 + \\ & \phi(c-1)\frac{\left(\delta_G(3\phi+2k) - \phi^2\gamma_G(3\phi+4k)\right)c - \left(\gamma_G\delta_G(3\phi-2k)(\phi+k)^2\right)}{(D_2(c))^4}\sigma_\varepsilon^2 \Bigg), \end{aligned}$$

and from (4.11), $\sigma_\varepsilon^2 = -\frac{(ck-(k+\phi))(D_2(c))^3}{\phi^2(k+\phi)(c-1)(D_1(c))^3}\bar{g}^2$. Substituting this formula in the previous equality and operating

$$\frac{\partial F}{\partial \phi}(c^*, \phi) = \frac{q(c^*)}{\phi(\phi+k) D_2(c^*) (D_1(c^*))^4}\bar{g}^2, \tag{4.12}$$

where

$$q(c) = q_3 c^3 + q_2 c^2 + q_1 c + q_0,$$

with

$$
\begin{aligned}
q_3 &= -k\left(3\phi+2k\right)\left(\delta_G+\phi^2\gamma_G\right)^2, \\
q_2 &= \left(\phi+k\right)\Big(2\left(\phi+k\right)\left(\delta_G+\phi^2\gamma_G\right)^2 \\
&\quad -k\gamma_G\delta_G\left(\delta_G\left(5k\phi-3\phi^2+4k^2\right)+\phi^2\gamma_G\left(11k\phi+3\phi^2+4k^2\right)\right)\Big), \\
q_1 &= \gamma_G\delta_G\left(k+\phi\right)^2\Big(k\delta_G\left(4k+3\phi\right)+2\phi^2\left(\phi^2\gamma_G-2\delta_G\right) \\
&\quad +k\gamma_G\left(\phi^2\left(4k+9\phi\right)-2k^2\delta_G\left(k+\phi\right)\right)\Big) \text{ and} \\
q_0 &= k\gamma_G^2\delta_G^2\left(2k-\phi\right)\left(\phi+k\right)^4.
\end{aligned}
$$

Note that

$$q\left(\frac{\phi+k}{k}\right)<0 \text{ and}$$

$$
\begin{aligned}
q(1) = {} & 3\phi^2\left(\delta_G^2+\phi^4\gamma_G^2+2\phi^2\gamma_G\delta_G+8\phi^4\gamma_G^2\delta_G\right)+ \\
& \phi\left(k-\phi\right)\Big(\gamma_G^2\delta_G^2k\left(k+\phi\right)^3+2\gamma_G^2\delta_G\phi^2\left(6k\phi+11\phi^2+k^2\right) \\
& +\phi^4\gamma_G^2+2\gamma_G\delta_G^2\left(k+\phi\right)\left(k+2\phi\right)+2\phi^2\gamma_G\delta_G+\delta_G^2\Big).
\end{aligned}
$$

Combining these results and (4.12), we can conclude that if σ_ε^2 is low enough, as c^* is close to $\frac{\phi+k}{k}$, then $\frac{\partial F}{\partial \phi}(c^*,\phi)<0$, and hence, $\frac{\partial c^*}{\partial \phi}>0$. In contrast, if σ_ε^2 is high enough, then c^* is close to 1. Notice that there are parameter configurations (for instance, $k>\phi$) such that $q(1)>0$, which implies that $\frac{\partial F}{\partial \phi}(c^*,\phi)>0$, and hence, $\frac{\partial c^*}{\partial \phi}<0$. Consequently, we show that $\frac{\partial c^*}{\partial \phi}<0$ may hold when σ_ε^2 is high enough. ■

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