Monetary and Fiscal Institutional Designs

Abstract

Two investment decisions in economic institutions are feasible; investments in monetary institutions in the form of delegation of monetary policy to a more conservative or independent central bank, and investments in fiscal capacity, in the form of combating bureaucratic corruption and its consequent fiscal revenue leakages. Within this framework, we investigate the interactions among those two institutional decisions and the obtained institutional structure. The findings provide support of strategic complementarities; investments in monetary and fiscal institutions reinforce each other. In addition, we identify a set of determinants that impact on the government's decisions to improve economic institutions, particularly, the structure and intensity of the initial corruption level, the amount of distortions caused by taxation and the policymaker's goals and preferences across its objectives.

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Introduction

Economic institutions and their design are of vital importance to economic outcomes. As such, institutional reforms are promoted as a way of reshaping incentives and improving economic performance and growth. In the past couple of decades various reforms have received considerable attention among developing, transition and emerging economies. This paper focuses on the determination and interaction between two particular investment decisions in economic institutions; investments in monetary institutions in the form of delegation of monetary policy to a more conservative and/or purely independent central bank, and investments in fiscal capacity, in the form of combating bureaucratic corruption and its consequent fiscal revenue leakage. Indeed central bank reforms and anti-corruption strategies have been very high in the agenda of both developing and developed countries.

On the monetary policy side, central bank independence is widely accepted as the institutional remedy that 'ties' the hands of the government and eliminates the inflationary bias (Barro and Gordon, 1983; Rogoff, 1985). A great number of central banks' statutes have been rewritten, strengthening their independent status and, at present, around thirty central banks operate under a highly autonomous inflation-targeting framework. Nonetheless, the monetary performance of these countries has been very diverse. With the recent consensus that corruption is a symptom of poor governance, the study of corruption and anti-corruption policies has reached high in the research and policy agenda of international organisations and many transition or emerging market economies for the past couple of decades.[1] A number of international agencies and academic experts have advocated a comprehensive approach to fighting corruption around the globe and substantial resources have been devoted to this end. However, the assessment of anti-corruption programmes provides for mixed results with regards to their effectiveness and various discussions on how such strategies can be improved.

Within the macroeconomic literature, a number of contributions (initiated by Sargent and Wallace (1981) and Alesina and Tabellini (1987)) have established the importance of fiscal policy in the determination of the optimal monetary institutional design. However, what has received less attention is the importance of fiscal institutions. Bureaucratic corruption and its implied limits on fiscal capacity can shape the fiscal and financing decisions of the government, which will in turn affect monetary policymaking.[2] The macroeconomic literature on corruption mainly focuses on its impact on economic growth, identifying various indirect channels, within endogenous growth models, lacking, however, a systematic analysis of its impact on macroeconomic policymaking. At the same time, anti-corruption policies are analysed in a more policy-oriented framework.

[1] See for instance, Brinkerhoff (2000), Huther and Shah (2000) and Doig, Watt, and Williams (2006).

[2] Huang and Wei (2006) and Dimakou (2006) show this in a static and dynamic set respectively. Acemoglu, Johnson, Querubin, and Robinson (2008) and Dimakou (2010) provide empirical evidence.

This paper attempts to bring the literatures on central bank independence and anti-corruption together and assess the interactions among those two reform decisions, the conditions under which they will be undertaken and their implications on the monetary and fiscal policy mix. In a two-period setting, the fiscal authority sets taxes, debt and government spending, while the monetary authority sets inflation in each period. We denote these as the policy decisions. In addition, the fiscal authority is allowed both to delegate a more conservative central bank and combat bureaucratic corruption; we denote these decisions as the investment decisions. We analyse the determination of these decisions under distinct institutional designs in which monetary policy is able to pre-commit (Second Best), is set discretionary (Discretion) and may be delegated to a weight-conservative and/or purely independent central bank (Decentralisation). In this context, we explore (i) how optimal investment in fighting corruption compares under the different institutional designs, (ii) and more importantly, how the two investment decisions interact within the decentralised regimes.

Our paper builds on the static Huang and Wei (2006) framework allowing for borrowing and assessing systematically the incentives to improve economic institutions. We find that the commitment setting is more conducive to investing in fiscal capacity with borrowing playing a positive role. The discretionary regime under-invests in fighting corruption due to both the inflationary bias incentive and debt policy. Decentralising monetary and fiscal policies enhances investment in both institutions, relative to discretion, and replicates the second best closely. The government delegates a more conservative central bank and fights corruption more. Moreover, we also provide evidence of strategic complementarities[3] among the two investment decisions. This is of genuine economic interest as it implies that improvements in monetary and fiscal institutions reinforce each other. Alternatively, a backwards step in one reform may impact the other reform negatively. Given that, we identify a set of structural determinants that impact on the government's decisions to improve economic institutions, namely, the structure and initial level of corruption, the amount of distortions caused by taxation, and the policymakers' preferences across its objectives.

This work is linked to three literatures. The first one focuses on fiscal corruption and the macroeconomic policy mix, and the closest paper to ours is Huang and Wei (2006). Unlike theirs, we allow for intertemporal linkages and investigate improvements in economic institutions under different institutional designs. The second strand covers the role of debt in a macro policy game, as done in Beetsma and Bovenberg (1997). Although they focus on debt dynamics, they abstract from corruption issues. The third looks at policy choices as constrained by past investments in state capacity and analyses the determinants of the latter explicitly. We follow the approach of Besley and Persson (2009)[4], distinguishing between economic policy and investment decisions,

[3]As defined by Bulow, Geanakoplos, and Klemperer (1985).

[4]They examine strategic complementarities among investments in legal and tax capacity in a structurally different game theoretic model.

and investigate their determination and interaction.

The remaining of the paper proceeds as follows. Section 2 sets the model and the time structure of the game. Section 3 presents each institutional design (second best, discretionary and decentralised regimes) and provides preliminary empirical evidence on the evolution of the two investment decisions during the past couple of decades. Section 4 concentrates on the equilibrium under each regime focusing on the determination and comparison of optimal investment decisions. Section 5 presents the numerical results, and Section 6 concludes.

2 Model

The model builds on Alesina and Tabellini (1987) and Huang and Wei (2006). There are three players in the economy that live for two periods. The private sector behaves competitively, rather than strategically, and sets inflation expectations. The government is responsible for the current fiscal policy outcomes, setting taxes, government spending and debt, as well as for the investment decisions of delegating monetary policy to a more conservative central bank and fighting corruption. Finally, when applicable, the central bank deals with monetary policy by setting inflation directly. Our framework departs from Alesina and Tabellini's (1987) and Huang and Wei's (2006) in two important ways: we consider a two period dynamic environment in which the government is allowed to issue debt and we allow for a systematic modeling of an anti-corruption policy.[5]

2.1 Private Sector: *Production, wage setting and aggregate supply*

The economy is characterised by a continuum of firms that are both price and wage takers and seek to maximise their net of taxes profits. Taxes (τ_t) are incorporated in the model as a fraction on the firms' revenues and thus distort the behaviour of firms. The private sector (individuals) sets nominal wage contracts one period in advance, in a competitive labour market, which is thus populated by a continuum of uncoordinated small agents. In this setting, the best individuals can do is predict inflation expectations correctly. The aggregate supply of the model is given by a modified supply curve:

$$y_t = y_n + a(\pi_t - \pi_t^e) - b\tau_t \tag{1}$$

where y_t shows the aggregate of log output, y_n is the level of log output that would prevail in the absence of monetary policy shocks and taxation, π_t and π_t^e are current and expected inflation and τ_t is the tax rate. The slope of the Philips curve, $a > 0$, captures the impact of unanticipated monetary policy, and in this simple model specification,

[5]Huang and Wei (2006) discuss the possibility of strengthening institutional quality in a static model and only under the commitment setting. Beetsma and Bovenberg (1997) develop a two period model, but without considering corruption issues.

depends on the one period fixed wage rigidities and the labour share in the production function. b measures how distortionary taxes are.[6]

The private sector aims at the market-determined level of output $(y_n - b\tau_t)$, which is distorted by taxation. We abstract from imperfections in both the goods and the labour markets, and concentrate on the effects of distortionary taxation on the policymakers decision making. As noted by Alesina and Tabellini (1987) distortionary taxation alone can generate the time-inconsistent monetary policy.

2.2 Fiscal Authority

The government provides public goods and services, having at its discretion taxation and/or borrowing. Taxes are levied on the firms' revenues and are distortionary. The government's objective function is given by an augmented but otherwise conventional loss function, with a negative sign in order to represent 'social welfare'. Benigno and Woodford (2004) justify this widely assumed specification by showing that, in a new Keynesian framework, a Taylor approximation to the households utility can match the loss function, given that the weights on inflation and output are appropriately set.

$$U^g = -\frac{1}{2}\sum_{t=1}^{2}\beta^{t-1}u_t = -\frac{1}{2}\sum_{t=1}^{2}\beta^{t-1}\left[\pi_t^2 + \lambda_1(y_t - y_n)^2 + \lambda_2(g_t - g^*)^2\right] \tag{2}$$

where $\lambda_i > 0,$ for $i = 1, 2$, and $u_t = \pi_t^2 + \lambda_1(y_t - y_n)^2 + \lambda_2(g_t - g^*)^2$ is the instantaneous loss function. The weights on the function's arguments are set relative to inflation. Hence, λ_1, λ_2 correspond to the weight relative to inflation the government puts on output and government spending respectively. The objective function comprises of three arguments:

(i) inflation deviations from its (zero) target. Despite the benefits of inflation on revenues (seigniorage) the bliss inflation target is set to price stability.

(ii) output deviations from the non-distortionary level of output, y_n. Thus, the difference in the output goals between the private sector $(y_n - b\tau_t)$ and the fiscal authority (y_n) is the source of the inflation bias. With no distortions $(b = 0)$ there is no output goal conflict, and hence no time-inconsistency problem.

(iii) government spending deviations from its target, $0 < g^* < 1$, which, following Debelle and Fischer's (1994) interpretation, represents the optimal share of non-distortionary output to be allocated on public goods provision, if non-distortionary taxes were available.

The government sets the current fiscal instruments; tax rate, government spending and debt in each period, $\{\tau_t, g_t, d_t \quad \text{for} \quad t = 1, 2\}$, and at the beginning of period

[6] As in Alesina and Tabellini (1987), the derivation of the aggregate supply curve implies that $a = b$. We allow for the impact of monetary $(\pi_t - \pi_t^e)$ and fiscal (τ_t) policies on aggregate activity to differ $(a \neq b)$ to capture the individual importance of each factor and manage direct comparisons with related recent works.

1, it also decides whether to invest in improved monetary and fiscal institutions, κ (delegation parameter) and f_1 (anti-corruption effort).

The monetary policy reform consists of the government choosing the relative weight on inflation (κ) in the central bank's objective function, which is otherwise the same as its own. More discussion on this investment decision will follow in section 3.4, where the delegation regime is fully analysed. As regards the investment in improving fiscal capacity, the government decides on whether and on how much effort (f_1) to exert in fighting corruption.[7] Given that this investment choice is the main novelty of this model, we present it in more detail.

Bureaucratic corruption is controlled by the parameter $0 \leq \phi_t \leq 1$, which determines how much of the tax revenues never reaches the treasury (See equations (3) and (4) below). Hence, $\phi_t \tau_t$ corresponds to the available tax revenue base or effective taxation. When $\phi_t = 0$, there is full corruption and the whole revenue base is 'eaten up'. When $\phi_t = 1$, there is no corruption and all tax revenues are collected. Bureaucratic corruption, as in Blackburn, Haque, and Neanidis (2008) and Ghosh and Neanidis (2010), is captured here in the simple form of embezzlement of public funds. Corrupt bureaucrats either grab tax revenues or artificially inflate the costs of tax collection or the value of the government expenditure. This way, we capture in a simple manner the constraints corruption imposes on tax revenues and the government budget.[8]

The initial corruption level is predetermined and equal to ϕ_1. At the beginning of period 1, the government decides to exert effort, f_1, to combat corruption. This effort will have a positive and, for simplicity, certain impact on the second period, by allowing for a smaller portion of the tax revenue base to go 'wasted'. Hence, the second period corruption coefficient is endogenous and given by, $\phi_2 = \phi_2(f_1; \phi_1, \gamma)$. With,

$$
\begin{aligned}
&i)\ \phi_2'(f_1; \phi_1, \gamma) > 0 \qquad ii)\ \phi_2''(f_1; \phi_1, \gamma) \leq 0 \quad iii)\ \phi_2(0; \phi_1, \gamma) = \phi_1 \\
&iv)\ \phi_2(f_1^{\max}; \phi_1, \gamma) = 1 \quad v)\ \phi_2(0; 1, \gamma) = 1 \text{ and } \phi_1 \leq \phi_2 \leq 1;\ 0 \leq f_1 \leq f_1^{\max}.
\end{aligned}
$$

The unit efficiency coefficient, γ, represents the degree to which effort translates into improved fiscal capacity; the lower is γ, the less efficient is the government in reducing tax leakages. The size of γ will depend, among other things, on the government's ability to better control its bureaucracy (officials or parts of the government) and to set a more transparent and independent administrative and judicial structure.

Effort in fighting corruption comes with a cost; this consists of the monetary cost or the portion of the budget needed to be reallocated away from other provisions and towards putting in place a structure that is more efficient in controlling corrupt acts. Certainly, the cost of anti-corruption policies could take the form of loss of economic rents enjoyed by corrupt bureaucrats or the foregone rents that powerful interest groups

[7]Our modeling of corruption fits into the categorisation of Aidt (2003), in which the government (principal) is benevolent and the bureaucrats (agents) are corrupt. Hence, the government has the incentive to fight corruption.

[8]For empirical evidence see, for example, Tanzi and Davoodi (1997), Ghura (1998) and Imam and Jacobs (2007).

have been acquiring from corruption and lost tax revenue. However, we assume that the corrupt agents are of unit mass zero, and thus we do not include their losses into the social welfare function. See Huang and Wei (2006) or Hefeker (2010) for an example where corruption is added directly to the welfare function. The cost function is proportional to effort and given by, $C(f_1;\widetilde{\theta})$, where $\widetilde{\theta}$ is the unit cost coefficient and,

$$i)\ C'(f_1;\widetilde{\theta}) \geq 0 \qquad ii)\ C''(f_1;\widetilde{\theta}) \geq 0 \quad iii)\ C(0;\widetilde{\theta}) = 0 \quad iv)\ C(f_1^{\max};\widetilde{\theta}) < \infty.$$

Note that both the unit efficiency, γ, and the unit cost, $\widetilde{\theta}$, coefficients will depend on the structure of the corrupt bureaucracy. Although we abstract from the exact process of how corruption making takes place, the degree of corruption centralisation, how much it goes up in the hierarchy, how widespread it is, whether interest groups are involved or whether corrupt officials collude with firms to under-report their profits, are important characteristics of the corruption structure that will inevitably affect both the government's ability to reduce it and the costs incurred in doing so.

The implications of this modeling of the anti-corruption process on the budget constraint are as follows. Fighting corruption has a cost in the first period, which pays out in the second period in the form of reduced tax leakages. This implies that there is an increase in the first period financial requirement of the government, or it is as if the first period spending target has increased to provide for fighting corruption in addition to public goods. The benefits from first period efforts are observed through the second period government budget constraint ($\phi_2(f_1)$) and are hence indirectly incorporated in the second period objective function of the government. This set up, unlike in Huang and Wei (2006), creates a new intertemporal linkage and captures the fact that outcomes from anti-corruption programmes take time to materialise. When setting the effort level in the first period the government should take into account the impact it would have on second period's corruption level, and hence on second period's taxation, inflation and overall social welfare.

The government finances its spending, anti-corruption efforts and debt repayments through taxes, seigniorage, and newly issued debt. In this two-period model, debt is indexed, matures after one period and the government cannot issue new debt in period 2 ($d_2 = 0$). The costs in fighting corruption, $C(f_1)$, only occur in period 1, since $f_2 = 0$. The government's budget constraint in each period reads[9]

$$g_1 = \pi_1 + \phi_1\tau_1 + d_1 - (1+\rho)d_0 - C(f_1) \tag{3}$$

$$g_2 = \pi_2 + \phi_2\tau_2 - (1+\rho)d_1 \tag{4}$$

where g_t, d_t, d_{t-1}, θ are expressed as shares of a non-distortionary level output ($\bar{Y}$).

[9]Money demand is assumed to be independent of fiscal policy, as in Beetsma and Bovenberg (1997). Thus, money growth corresponds to inflation and the fiscal authority is not subject to time-inconsistencies.

2.3 Monetary Authority

The central bank is responsible for monetary policy and controls inflation perfectly. The monetary authority is subject to time-inconsistency problems, since from (1) it can use surprise inflation to stimulate output, which is considered 'too low' due to distortionary taxation. The objective function of the central bank is:

$$V^{cb} = -\frac{1}{2}\sum_{t=1}^{2}\beta^{t-1}v_t = -\frac{1}{2}\sum_{t=1}^{2}\beta^{t-1}[\kappa\pi_t^2 + \lambda_1(y_t - y_n)^2 + \lambda_2(g_t - g^*)^2] \qquad (5)$$

where $v_t = \kappa\pi_t^2 + \lambda_1(y_t - y_n)^2 + \lambda_2(g_t - g^*)^2$ is the instantaneous utility and $\kappa \geq 1$ represents the central bank's weight on inflation aversion.

With $\kappa = 1$, both authorities share the same objective function, and hence we have a centralised authority being responsible for both monetary and fiscal policy. Clearly, under this framework, the policymaker is facing the optimal policy mix and there is no disagreement regarding the conflicting objectives. In the case where $\kappa > 1$ monetary policy is delegated to a weight-conservative central bank that is more averse to inflation, as in Rogoff (1985).

With the explicit incorporation of fiscal policy, the third argument in the central bank's objective (essentially $\lambda_2 > 0$) represents the degree of fiscal dominance of monetary policy and thus the extent in which the delegated central bank is 'forced' to take fiscal considerations into account when setting its monetary policy. Thus, within the decentralised framework we can also examine the case of a purely independent central bank, where the third argument in (5) drops ($\lambda_2 = 0$). In line with the literature on central bank independence this corresponds to instrument independence, as opposed to goal independence since the central bank shares the same goals as the government.[10]

2.4 Different Regimes and Timing of Events

As standard in this literature, starting off with the (infeasible) non-distortionary institutional setting (first best), we go on to examine the case where a centralised authority is able to pre-commit setting optimal policy and anti-corruption decisions in an environment with distortionary taxes. This gives rise to the second best solution (SB) of the model, which will act as the benchmark of comparison. We then move on to analyse the case in which the centralised authority has no available commitment technology (discretion). Improvements upon the discretionary regime are examined by allowing for monetary policy delegation to a more conservative central bank. This is the regime where investment decisions in improving both the monetary and the fiscal institutions takes place. A special case of this regime is delegation to an independent central bank.

Regarding the timing of events, investment decisions always follow a Ramsey allo-

[10]Coordination and decentralisation of policies has been parametarised in different ways within this literature, with consistent results. See for example, Beetsma and Bovenberg (1997), Eijffinger and Hoeberichts (2008) and Hughes Hallett and Weymark (2005).

cation; being decided at the beginning of the game. Then, depending on which regime is in place, the timing of policy decisions will differ. The economy starts out with a given level of fiscal capacity, ϕ_1, as well as a given set of relative weights on the 'society's' objective function, λ_1, λ_2.

1. At the beginning of period 1, the government sets each investment decision in
   (a) fighting corruption, f_1, and
   (b) (when applicable) delegating monetary policy, κ
2. Given that 1.(b) is in place the central bank is formed
3. The private sector forms its first period inflation expectations
4. The government and (when applicable) the central bank set period 1 fiscal (τ_1, g_1, d_1) and monetary (π_1) policies
5. Policy outcomes, output and new fiscal capacity level are realised and period 1 finishes
6. At the beginning of period 2, the individuals set their second period inflation expectations
7. The government and (when applicable) the central bank set fiscal (τ_2, g_2) and monetary (π_2) policies
8. Policy outcomes and output are realised

Note that for both the commitment and the discretionary regimes, there is no investment in monetary institutions, hence no central bank, by construction. The Nash equilibrium in each regime is derived by backward induction.

3 Regimes

There are three main regimes: Commitment (SB), Discretionary and Decentralisation of monetary and fiscal policy. Before analysing them, we briefly present the first best institutional arrangement.

3.1 First Best

In the first best institutional arrangement there is no corruption and no time-inconsistent monetary policy. With lump-sum taxes aggregate supply is no longer distorted by taxation and there is no link from one period to the other, which implies that debt, tax and anti-corruption policies are redundant (indeterminate). The first best outcome results in zero inflation, and output and government spending gaps. Taxes and debt are interchangeable, since any of the two can be used to cover the desired level of government spending. Even in the presence of corruption, there is no need to invest in fighting fiscal leakages, since corruption is only increasing the amount of lump-sum taxes needed to meet all targets.

3.2 Second Best

With non-existent lump-sum taxes, the first best solution is infeasible. The second best (SB) of the model is derived from a centralised authority that is able to pre-commit to its policies when taxes are distortionary. The commitment case is a pure Ramsey allocation, since all investment and policy decisions are decided at the beginning of period 1. There is no investment in monetary institutions and in that sense the optimal policy mix is achieved, since there are no conflicts in terms of goals or priorities.

In the beginning of period 1 the government maximises its intertemporal objective function with respect to policy and investment variables.

$$\max_{\tau_t,\pi_t,d_t,f_t} = -\frac{1}{2}\sum_{t=1}^{2} u_t = -\frac{1}{2}\sum_{t=1}^{2}\beta^{t-1}\left[\pi_t^2 + \lambda_1(y_t - y_n)^2 + \lambda_2(g_t - g^*)^2\right]$$

$$\text{Subject to:} \quad \pi_t^e = \pi_t; \quad y_t - y_n = -b\tau_t \quad \text{and}$$

$$g_t - g^* = \pi_t + \phi_t\tau_t + d_t - F_t \quad \text{for} \quad t = 1, 2$$

where $F_t = (1+\rho)d_{t-1} + g^* + C(f_t)$ shows the government's financial requirements for $t = 1, 2$. Recall that since this is a two period model $d_2, f_2 = 0$. To facilitate comparisons with the other institutional settings, this problem can be equivalently decomposed into an optimisation first with respect to policy decisions and then with respect to investment decisions. Letting $\mathfrak{z} = (a, b, \lambda_1, \lambda_2, \gamma, \theta, g^*)$ denote the vector with all structural parameters and $u_t^{*,\text{SB}}(f_1; \mathfrak{z})$ be the optimised with respect to policy decisions instantaneous loss function, then the investment decision obtains from solving

$$\max_{f_1} -\frac{1}{2}\sum_{t=1}^{2} u_t^{*,\text{SB}}(f_1; \mathfrak{z}) = -\frac{1}{2}[u_1^{*,\text{SB}}(f_1; \mathfrak{z}) + \beta u_2^{*,\text{SB}}(f_1; \mathfrak{z})].$$

3.3 Discretionary Regime

When pre-commitment is not available the output boost channel of unanticipated inflation is present. Policy decisions are made sequentially and monetary policy is subject to the well-known time-inconsistency behaviour. This is the discretionary regime, in which, again, there is no investment in a monetary policy reform; only an anti-corruption decision is allowed. The model is solved as follows. In *period 2*, the centralised authority sets fiscal and monetary policies according to:

$$\max_{\tau_2,\pi_2} -\frac{1}{2}u_2 = -\frac{1}{2}\left[\pi_2^2 + \lambda_1(y_2 - y_n)^2 + \lambda_2(g_2 - g^*)^2\right]$$

$$\text{Subject to:} \quad y_2 - y_n = a(\pi_2 - \pi_2^e) - b\tau_2$$

$$g_2 - g^* = \pi_2 + \phi_2\tau_2 - F_2; \ (\text{with } F_2 = (1+\rho)d_1 + g^*)$$

Upon these, individuals form their expectations and period 2 finishes. Similarly, in *period 1* the government chooses its policy instruments taking people's expectations as given and assuming that optimal period 2 policies will be followed,

$$\begin{aligned}
\max_{\tau_1,\pi_1,d_1} -\frac{1}{2}u_1 &= -\frac{1}{2}\left[\pi_1^2 + \lambda_1(y_1 - y_n)^2 + \lambda_2(g_1 - g^*)^2 + \beta u_2^{*,\mathrm{DIS}}(d_1, f_1; \mathfrak{z})\right] \\
\text{Subject to:} \quad & y_1 - y_n = a(\pi_1 - \pi_1^e - \tau_1) \\
& g_1 - g^* = \pi_1 + \phi_1\tau_1 + d_1 - F_1; \text{ (with } F_1 = (1+\rho)d_0 + g^* + C(f_1)) \\
& \text{Optimal period two policies will be followed } (u_2^{*,\mathrm{DIS}}(d_1, f_1; \mathfrak{z}))
\end{aligned}$$

After first period policy decisions and expectations are set, the government decides on the optimal investment in fiscal capacity by maximising optimised (in terms of policies) welfare

$$\max_{f_1} U^{*,\mathrm{DIS}}(f_1; \mathfrak{z}) = -\frac{1}{2}[u_1^{*,\mathrm{DIS}}(f_1; \mathfrak{z}) + \beta u_2^{*,\mathrm{DIS}}(f_1; \mathfrak{z})].$$

3.4 Delegation of Monetary policy

In this regime, investment in improving the monetary policy institutions is allowed. In line with the literature on central bank independence (initiated by Rogoff (1985)), delegation of monetary policy to a more conservative central bank can improve upon the discretionary policy outcomes, since under discretion the economy ends up with higher inflation and lower taxes compared to the second best. Moreover, in our framework, there can also be improvements in economic institutions, since the government may invest in improving both fiscal capacity and monetary policymaking. Indeed, central bank and anti-corruption reforms have been promoted in many countries in the past couple of decades.

The decentralised outcomes are obtained as follows. At the beginning of period one the government optimally sets its investment decisions on both monetary and fiscal institutions (Ramsey allocation). Recall that the main difference between those two investment decisions is that reforming the monetary structure and delegating a central bank with optimal weight, κ, takes effect immediately, although the results of investing in fighting corruption show only in the second period. Policy decisions take place sequentially. More precisely, in *Period 2*, the government chooses its fiscal instrument, τ_2 and the central bank sets monetary policy, π_2 according to

$$\begin{aligned}
\max_{\tau_2} -\frac{1}{2}u_2 &= -\frac{1}{2}\left\{\pi_2^2 + \lambda_1(y_2 - y_n)^2 + \lambda_2(g_2 - g^*)^2\right\} \\
\max_{\pi_2} -\frac{1}{2}v_2 &= -\frac{1}{2}\left\{\kappa\pi_2^2 + \lambda_1(y_2 - y_n)^2 + \lambda_2(g_2 - g^*)^2\right\} \\
\text{Subject to:} \quad & y_2 - y_n = a(\pi_2 - \pi_2^e) - b\tau_2 \\
& g_2 - g^* = \pi_2 + \phi_2\tau_2 - F_2
\end{aligned}$$

The private sector forms its expectations in accordance with the fiscal and monetary authorities' policy behaviours and the period finishes. Similarly, in *Period 1*, the government sets τ_1, d_1 and the central bank first period inflation taking expectations and period 2 policies as given. This obtains the overall optimised social welfare as a function of the investment decisions and all structural parameters ($\mathfrak{z}$) which is maximised with respect to f_1, κ

$$\max_{f_1,\kappa} U^{*,\text{DMC}}(f_1,\kappa;\mathfrak{z}) = -\frac{1}{2}[u_1^{*,\text{DMC}}(f_1,\kappa;\mathfrak{z}) + \beta u_2^{*,\text{DMC}}(f_1,\kappa;\mathfrak{z})].$$

Delegation of monetary policy to a more conservative and purely independent central bank corresponds to the modified monetary objective function with $\lambda_2 = 0$,

$$\widetilde{V}_t^{\text{ICB}} = -\frac{1}{2}\{\kappa\pi_t^2 + \lambda_1(y_t - y_n)^2\} \quad \text{for} \quad t = 1, 2$$

Pure central bank independence implies that the monetary authority is not fiscally dominated, achieving its monetary target without taking the budgetary needs of the government into account. In this case, the conflicts among the two policymakers are increased, since the objective functions differ also in their goals, in addition to the prioritisation of goals. Monetary policy setting is concerned only with the output gap, not the fiscal budget. In practice, one of the most important provisions in central bank reforms is the moderation (small λ_2) and ultimately prohibition ($\lambda_2 = 0$) of debt monetisation and direct credit to the government.

Before moving on to analyse the determination and interaction of those investment decisions under different institutional regimes, we have a preliminary look on how those two reforms have been evolving over time in practice.

3.5 Evolution of monetary and fiscal institutional reforms

In the past couple of decades, the majority of central bank's acts have been re-written strengthening the economic and political independence of the monetary authority. At the same time, anti-corruption policies have been a priority in both international and national levels. Apart from international conventions (UN, OECD, Council of Europe)[11] and several regional anti-corruption initiatives, anti-corruption programmes and commissions have been established in many countries and sizeable resources have been allocated to fighting bureaucratic corruption. Indicatively, we look at the direct correlation between central bank reforms and the evolution of corruption indices, as an indicator of anti-corruption reforms to get a preliminary idea of how improvements on those two institutional dimensions have been evolving through time.

We collect data that measure the degree of central bank independence and the level of corruption for 45 countries. Central bank independence is measured by the

[11] OECD Convention on Combating Bribery of Foreign Public Officials (1997), Council of Europe Criminal Law Convention on Corruption (2002), United Nations Convention against Corruption (UNCAC - 2005)

Cukierman Index[12] reconstructed in Polillo and Guillén (2005) to assess the magnitude of reforms during the 1990s. Indeed, following some reforms during the mid 1980s, the next decade has witnessed various central bank reforms in all geo-economic regions. We use the difference in the index before and after the change in the Act to identify the magnitude of the reform. With regards to the evolution of corruption over time, we use the well known Corruption Perception Index (CPI) of Transparency International, and the cardinal corruption measure (DKM) developed by Dreher, Kotsogiannis, and McCorriston (2007). The former is a perception-based index providing for subjective ratings of respondents (country experts) from a set of different surveys and measured in a scale from 0 (full corruption) to 10 (no corruption). The latter is a measure of corruption in terms of losses as a share of GDP per capital derived from a structural equation method in which corruption is treated as a latent variable directly related to its underlying causes and effects. It ranges from -0.9 (very low corruption) to 0.3 (high corruption).

[PUT Figure 1 HERE]

Figure 1: Central Bank Independence and Corruption

(a) DKM difference between 1991/97 and 1981/85; (b) DKM difference between 1991/97 and 1986/90 (c) CPI difference between 2003 and 1998 (for Central Bank Reforms before 1997), and difference between 2006 and 2000 (for reforms after 1997); (d) CPI in percentage changes

Figure 1 presents the results. The DKM corruption index shows a correlation with central bank reforms of 0.5 for 36 countries for which data were available (using both the differences between 1991/97 vs 1981/85 and 1991/97 vs 1986/90). The Spearman Rank coefficient is a bit higher and overall we observe a significant relation between improvements in monetary authority independence and corruption control. The observed correlation between central bank reforms and the perception based corruption index (CPI) is lower (0.3 in differences and 0.4 in percentage changes), but still statistically significant for a set of 45 countries. The weaker correlation with the use of CPI can be explained by the inherent issues of such subjective measures especially when employed over time ('inertia' in perceptions, different samples/ methodologies used over time, low correlation between perceived and actual corruption).

Further, to the extent that anti-corruption efforts and resources allocated to fighting corruption are higher than the evolution of corruption indices suggest, the observed correlations above can be underestimated. Indeed, there is growing evidence that despite anti-corruption efforts -broad range of legal, institutional and administrative reforms, anti-corruption agencies and anti-bribery initiatives- their effects on corruption have not yet fully materialised.[13]

[12]The index was developed by Cukierman, Webb, and Neyapti (1992) aggregating 16 characteristics of central bank charters. It ranges from zero (no independence) to one (maximum independence).

[13]For example see Doig, Watt, and Williams (2007), Heilbrunn (2004), Dionisie and Checchi (2008).

Overall, the data suggest that both reforms in central banking and anti-corruption initiatives have been taken up jointly. Thus, a more detailed investigation of their interactions and determinants is of great importance. This is done in the following section.

4 Optimal Policy and Investment Decisions

Optimal investment decisions in each regime are obtained by maximising the optimised, with regards to policy decisions, overall welfare.[14] Derivation details are found in Appendix B. With the exception of the commitment outcome, we cannot obtain analytical results. Nonetheless, we may draw a set of analytical propositions regarding the optimal choices on investing in reforming monetary and fiscal institutions. In addition, we perform a set of comparative statics exercises employing numerical simulations.

4.1 Analytical Results

The functional forms assumed for the cost and effort functions are:

$$C(f_1) = \theta f_1^2 \tag{6}$$

$$\phi_2(f_1) = (\phi_1^2 + \gamma f_1)^{1/2} \tag{7}$$

The results derived in this section, unless otherwise stated, do not depend on these particular specifications; they only rely on the properties of $C'(f_1) \geq 0$ and $\phi_2'(f_1) > 0$.

Second Best (SB)

Second Best optimal effort is set in accordance to:

$$\max_{f_1^{\mathrm{SB}}} U^{*,\mathrm{SB}}(f_1; \mathfrak{z}) \quad \text{s.t.} \quad 0 \leq f_1 \leq f_1^{\max}$$

$$\text{with} \quad \frac{dU^{*,\mathrm{SB}}}{df_1} = \mathrm{FOC}_{f_1}^{\mathrm{SB}} = \mathrm{MULT}_{\mathrm{SB}} \left\{ -C'(f_1) + \frac{\lambda_2 \phi_2 \phi_2' [\mathrm{FR} + C(f_1)]}{D_2(1 + \beta(1+\rho)^2 D)} \right\}. \tag{8}$$

$\mathrm{MULT}_{\mathrm{SB}}$ is a multiplicative term that is strictly positive for all values of f_1 within its domain. For more details and the definitions of FR, D_2, D see Appendix B.1.

Proposition 1. *Only under the Commitment regime there will always be some positive optimal investment in fighting corruption.*

Proof

See Karush-Kuhn-Tucker (KKT) conditions for the SB problem in Appendix B.1. The proof relies on the assumption that $C'(f_1) = 0$ when $f_1 = 0$.

□

[14] Appendix A presents optimal policy decisions under each regime for given investment decisions.

Under the second best (SB) setting, the fiscal authority will always invest in anti-corruption efforts and decrease fiscal leakages; optimal f_1^{SB} is strictly positive for all parameter values in $\mathfrak{z}$. This result is unique to the commitment regime, implying that there is more scope in fighting corruption under the SB relative to the other institutional settings examined below.

In a static framework (with no debt) Huang and Wei (2006) use different functional specifications and also derive the optimal anti-corruption effort under the commitment regime (they do not analyse anti-corruption under other regimes as we do). Here, we develop a dynamic setting in which both borrowing and anti-corruption efforts have intertemporal effects, hence straightforward comparisons are not easy. Nonetheless, the role of borrowing becomes important. Debt allows for a better intertemporal allocation of policies (inflation and taxation) and more investment in improving fiscal institutions. Issuing debt in the first period facilitates the financing of the extra government expenditure required (cost of anti-corruption programme); the debt can then be re-paid in the second period taking advantage of the more efficient tax collection system. In addition, borrowing in period one can also be viewed as a better tool for meeting the government expenditure target, instead of taxation or seigniorage, in anticipation of a lower corruption level in the future. Apart from the intertemporal anti-corruption effect[15], debt plays a smoothing role by taking into consideration the differences between period one and period two government financial requirements $((1+\rho)d_0+g^*+C(f_1)-g^*)$ and balancing out policy outcomes in periods one and two. Thus, borrowing, in the context of investment in the fiscal capacity, plays a positive role under the commitment regime; it enhances the anti-corruption efforts and allows for a better allocation of policy decisions between the two periods.

Investing in attaining full fiscal capacity will be optimal when the unit cost of fighting corruption (θ) is small enough. We can pinpoint the θ lower bound[16] below which full effort in fighting corruption is exhibited using the functional forms as specified in (6) and (7). This lower bound is given by[17]

$$\theta_L^{\mathrm{SB}} = \frac{\gamma\lambda_2 \mathrm{FR}}{\left(\frac{(1-\phi_1^2)}{\gamma}\right)\left\{4D_2^m(1+\beta(1+\rho)^2D^m)-(1-\phi_1^2)\lambda_2\right\}} > 0$$

where superscript m denotes the value of the expression when $f_1 = f_1^{\max}$.

Discretion

For the discretionary case, optimal f_1 is found by solving the following constrained problem,

[15] Intertemporal substitution also depends on the economy's time preferences in relation to the real return on assets ($\frac{1}{\beta}$ and $(1+\rho)$) and is the same for all institutional settings.

[16] θ_L^{SB} is derived by evaluating the FOC given by (8) for $f_1^{\max}$ and then solving for θ.

[17] Huang and Wei (2006) establish a similar unit cost lower bound in a static framework. They also find an upper bound for θ above which no effort in fighting corruption is put. In our case, no such bound exists. The results differ due to the unit cost specification; they assume a linear function, while we set a quadratic one.

$$\max_{f_1} \; U^{*,\mathrm{DIS}}(f_1;\mathfrak{z}) \quad \text{s.t.} \quad 0 \leq f_1 \leq f_1^{\max}$$

$$\text{with} \quad \frac{dU^{*,\mathrm{DIS}}(f_1;\mathfrak{z})}{df_1} = \mathrm{MULT}_{\mathrm{DIS}} \left\{ -C'(f_1)R_2 + \frac{\lambda_2\phi_2\phi_2'[\mathrm{FR}+C(f_1)]\widetilde{S}\tilde{s}}{(1+\beta(1+\rho)^2\Omega)\Omega_2} \right\} \tag{9}$$

$$\mathrm{MULT}_{\mathrm{DIS}} > 0 \quad \text{and} \quad \tilde{s} > 1 \quad \forall \quad 0 \leq f_1 \leq f_1^{\max}$$

Under discretion $f_1 = 0$ cannot be excluded as an optimal choice. Hence, given the structural parameters of the model, not investing in fighting corruption to improve fiscal institutions might be an optimal choice. This will certainly be the case whenever $\widetilde{S} \leq 0$. An interior solution requires that $\widetilde{S} > 0$. With $\widetilde{S} > 0$, $f_1^{\max}$ can be supported given that the unit cost coefficient of fighting corruption is small enough. (See Appendix B.2 for exact definitions of $\widetilde{S}, \tilde{s}$ and $\mathrm{MULT}_{\mathrm{DIS}}$, and a discussion on the sign of $\widetilde{S}$.) The lower bound on the unit cost coefficient, below which the discretionary central authority will be fully investing in fiscal capacity, is

$$\theta_L^{\mathrm{DIS}} = \frac{\gamma\lambda_2\widetilde{S}^m\tilde{s}^m\mathrm{FR}}{\left(\frac{1-\phi_1^2}{\gamma}\right)\{4R_2^m\Omega_2^m(1+\beta(1+\rho)^2\Omega^m) - (1-\phi_1^2)\lambda_2\widetilde{S}^m\tilde{s}^m\}}$$

where superscript m denotes the value of the expression evaluated at $f_1 = f_1^{\max}$ and the functional specifications for the cost and effort functions are given by (6) and (7). The cost bound depends on $\widetilde{S}^m$, the sign of which is uncertain, hence it can be negative, in which case $f_1^{\max}$ can never be supported as an optimal solution and the only solution is $f_1^{\mathrm{DIS}} = 0$.

Proposition 2. *The value of the unit cost of corruption that induces full investment in fiscal capacity is lower under the discretionary regime relative to the second best,*

$$\theta_L^{\mathrm{SB}} > \theta_L^{\mathrm{DIS}} \quad \textit{given that} \quad \frac{a}{b} \leq \frac{1}{\phi_1}$$

This indicates that the discretionary regime under-invests in fighting corruption relative to the Second Best.

Proof
See Appendix B.5

□

Even though analytical solutions for f_1^{SB} and f_1^{DIS} cannot be obtained, we can use the lower bounds on the cost coefficient to compare optimal efforts in fighting corruption among those two institutional designs. A lower θ_L signifies that it is harder for $f_1^{\max}$ to be the optimal choice. Thus, $\theta_L^{\mathrm{DIS}} < \theta_L^{\mathrm{SB}}$ implies that for the same θ, $f_1^{\mathrm{SB}} > f_1^{\mathrm{DIS}}$, as long as the difference in the slopes of the two first order conditions is not significant.[18] The condition provided for Proposition 2 ($\frac{a}{b} \leq \frac{1}{\phi_1}$) is a sufficient

[18] That is, the first order conditions for the range between 0 and $f_1^{\max}$ should not cross.

condition, not a necessary one. Indeed, in all the numerical simulations of section 4.3 we confirm that *(i)* $\theta_L^{\mathrm{SB}} > \theta_L^{\mathrm{DIS}}$ and *(ii)* $f_1^{\mathrm{SB}} > f_1^{\mathrm{DIS}}$, even when the sufficient condition does not hold.

The intuition for the occurrence of under-investment in the discretionary case is as follows. Under discretion, the unanticipated inflation to boost output channel is present. In a purely static setting ($d_1 = f_1 = 0$) discretion results in an inflationary and under-taxing bias; too much revenue is raised through inflation and too little through taxation compared to the second best institutional design (intratemporal distortions). Since, taxation is used less (in relation to the commitment outcome), the negative impact corruption has on tax revenues is not viewed as harmful. Therefore, when allowing for an anti-corruption investment the incentives to fight corruption and tackle the fiscal leakages are smaller. In addition, debt policy is also restraining the government from fighting corruption. Discretionary debt has what Beetsma and Bovenberg (1997) term a 'credibility effect', by which the government attempts to use debt to correct for the intratemporal discretionary distortions. Although first period expectations are taken as given, debt can still affect second period inflation expectations. The government has the incentive to disaccumulate debt (relative to commitment) to gain on second period credibility, by constraining second period inflation expectations and ultimately inflation. With an endogenous anti-corruption process, the intertemporal anti-corruption effect of debt is weakened by the credibility effect, since they move to opposite directions. The former tends to accumulate debt (in order to finance anti-corruption effort and increase second period taxation) while the latter tends to disaccumulate debt (in order to reduce the 'too high' second period inflation). Thus, the government is not willing to finance f_1 through excessive borrowing and under-investment occurs.

Having established that under an institutional framework in which the government operates centrally and discretionary, the incentive to combat corruption is lowered, we proceed to analyse the implications of decentralised monetary and fiscal policies.

Delegation of monetary policy to a more conservative central bank (DMC)

With decentralised policies we have,

$$\max_{f_1,\kappa} \quad U^{*,\mathrm{DMC}}(f_1,\kappa;\mathfrak{z}) \quad \text{s.t.} \quad 0 \le f_1 \le f_1^{\max}, \quad \kappa \ge 1$$
$$\max_{f_1,\kappa} \quad L^{\mathrm{DMC}} = U^{*,\mathrm{DMC}}(f_1,\kappa;\mathfrak{z}) + h_{f_1}^{\mathrm{dmc}}(f_1^{\max} - f_1) + h_{\kappa}^{\mathrm{dmc}}(\kappa - 1)$$

$$\text{with } \frac{\partial U^{*,\mathrm{DMC}}}{\partial f_1} = \mathrm{FOC}_{f_1}^{\mathrm{DMC}} = \mathrm{MULT}_{\mathrm{DMC}}\left\{-C'(f_1)C_2 + \mathcal{I}_1\widetilde{Q}\,q\right\} \tag{10}$$
$$\frac{\partial U^{*,\mathrm{DMC}}}{\partial \kappa} = \mathrm{FOC}_{\kappa}^{\mathrm{DMC}} = -\mathrm{mult}_{\mathrm{DMC}}\Big\{[b(\kappa-1) - a\phi_1]\mathcal{I}_2[b(\kappa-1) - a\phi_2]\mathcal{I}_3 q\Big\} \tag{11}$$

$$\text{and } \mathrm{MULT}_{\mathrm{DMC}},\ \mathrm{mult}_{\mathrm{DMC}},\ \mathcal{I}_1,\ \mathcal{I}_2,\ \mathcal{I}_3 > 0 \quad \forall \quad 0 \le f_1 \le f_1^{\max},\ \kappa > 1$$

Despite the fact that no closed form solutions can be obtained, we can derive a set of necessary and/or sufficient conditions for an interior solution to exist, and attempt to describe the nature of such a solution. Combining the requirements for an interior solution with the Karush-Kuhn-Tucker conditions for the whole characterisation of the maximisation problem, we state the following two propositions:

Proposition 3. *Under the DMC regime, setting $\kappa = 1$ is never optimal.*

Proof

See KKT conditions for DMC in Appendix B.3

□

The delegation regime with $\kappa = 1$ corresponds to the *ex ante* discretionary setting. However, as soon as the centralised authority is given the opportunity to delegate monetary policy, the *ex post* discretionary outcome is not optimal under any structural parameter values. A more conservative central bank is appointed. This result confirms Rogoff's (1985) argument within our dynamic setting with endogenous anti-corruption. Delegation of monetary of policy can improve upon the discretionary policy outcomes and align them closer to the commitment ones. A more inflation averse central bank ($\kappa > 1$) reduces the discretionary inflation and under-tax biases. In addition, the 'credibility' effect of debt is diminished, since delegation is a better way of replicating the commitment outcomes rather than debt.

Proposition 4. *Under the DMC regime, an interior solution will always give an optimal κ greater than 1, or a more conservative central bank, such that*

$$\kappa > 1 + \frac{a}{b}\phi_1$$

Proof

See analysis for an interior solution under DMC in Appendix B.3

□

This result implies that, other things being equal, an increase in ϕ_1 (better initial institutional quality), an increase in a (higher *ex ante* positive impact of unanticipated monetary policy on output) or a decrease in b (lower negative impact of tax distortions on output), would suggest a higher optimal κ (more conservative central bank). Lower corruption (higher ϕ_1) implies a more efficient tax system, thus a more inflation averse central bank is preferred, since revenues do not have to rely largely on inflation (seigniorage). For the same reasoning, taxes that do not highly distort output (lower b) also facilitate the appointment of a more inflation averse monetary authority. Lastly, when the unanticipated output boost channel is strong (high a), there is scope in making the central bank more conservative, as it will still have a higher incentive to generate inflation (through high a).[19]

Regarding the level of conservatism, in a static setting in which $\phi_1 = \phi_2 = \phi$ and no investment in fighting corruption takes place, the optimal degree of conservatism

[19]These effects are further discussed in Section 4.3 under the numerical simulations.

is $\kappa^{static} = 1 + \frac{a}{b}\phi_1$ and the commitment outcome is restored, as shown in Huang and Wei (2006). The same result would also prevail in our dynamic setting with $f_1 = 0$ and the same corruption level in both periods. When anti-corruption efforts are in place ($f_1 > 0$), the optimal degree of conservatism is strictly higher than the static one.[20] This is a way of confirming strategic complementarities, since more investment in improving the fiscal capacity also implies more investment in the monetary institutions (see 4.2 below). With regards to an upper bound on the optimal delegation parameter under DMC, κ^{DMC}, this can either be smaller or higher than $1+\frac{a}{b}\phi_2$, depending on the structural parameters of the model and the optimal effort to fight corruption. However, in all the numerical specifications analysed in the following section, κ^{DMC} is always found to be smaller than $1 + \frac{a}{b}\phi_2$.

As in the previous regimes, we can derive the lower value of the cost coefficient that would induce full investment in fighting corruption ($f_1 = f_1^{\max}$). This lower bound is now a function of the delegation parameter, κ.

$$\theta_L^{\text{DMC}} = \frac{\kappa\lambda_2\gamma\text{FR}\widetilde{Q}^m\tilde{q}^m}{\left(\frac{1-\phi_1^2}{\gamma}\right)\{4\Gamma_2^m C_2^m(1+\beta(1+\rho)^2\Gamma^m) - (1-\phi_1^2)\kappa\lambda_2\widetilde{Q}^m\tilde{q}^m\}}$$

In comparison to the discretionary regime, $\theta_L^{\text{DIS}} < \theta_L^{\text{DMC}}$, or equivalently $\frac{\partial\theta_L^{\text{DMC}}}{\partial\kappa} > 0$, indicates that optimal effort in fighting corruption is higher under DMC relative to discretion. The numerical analysis of section 4.3 verifies that anti-corruption incentives are higher under the decentralised regime. Hence, under the setting in which the government is given the option to decentralise monetary and fiscal policies, the government finds it optimal to (i) delegate a more conservative central bank ($\kappa^{\text{DMC}} > 1$) and (ii) invest more in improving its fiscal capacity ($f_1^{\text{DMC}} > f_1^{\text{DIS}}$) relative to the discretionary regime. These findings provide evidence that decentralisation can improve upon both investment decisions (relative to discretion) and that complementarities between the two institutional design decisions exist (more on this in section 4.2).

Independent Central Bank (ICB)

Finally, under delegation of monetary policy to a more conservative *and* fully independent central bank, in which case the central bank does not internalise budgetary considerations when setting monetary policy, the maximisation problem yields,

$$\max_{f_1,\kappa} \quad U^{*,\text{ICB}}(f_1,\kappa;\mathfrak{z}) \quad \text{s.t.} \quad 0 \le f_1 \le f_1^{\max}, \quad \kappa \ge 1$$

$$\max_{f_1,\kappa} \quad L^{\text{ICB}} = U^{*,\text{ICB}}(f_1,\kappa;\mathfrak{z}) + h_{f_1}^{\text{icb}}(f_1^{\max} - f_1) + h_{\kappa}^{\text{icb}}(\kappa - 1)$$

with

[20] Note that the boundary solution with $f_1 = 0$ and $k = 1 + \frac{a}{b}\phi_1$ is never possible and it would restore the the SB with $f_1 = 0$.

$$\frac{\partial U^{*,\mathrm{ICB}}}{\partial f_1} = \mathrm{FOC}_{f_1}^{\mathrm{ICB}} = \mathrm{MULT}_{\mathrm{ICB}} \left\{ -C'(f_1)V_2 + \mathcal{E}_1 \widetilde{K}\, k \right\} \tag{12}$$

$$\frac{\partial U^{*,\mathrm{ICB}}}{\partial \kappa} = \mathrm{FOC}_{\kappa}^{\mathrm{ICB}} = -\mathrm{mult}_{\mathrm{ICB}} \left\{ [b(\kappa-1) - a\phi_1]\mathcal{E}_2 + [b(\kappa-1) - a\phi_2]\mathcal{E}_3 k \right\} \tag{13}$$

and $\mathrm{MULT}_{\mathrm{ICB}},\ \mathrm{mult}_{\mathrm{ICB}},\ \mathcal{E}_1,\ \mathcal{E}_2,\ \mathcal{E}_3$ strictly positive in the domains of f_1, κ. More details can be found in Appendix B.4.

Proposition 5. *Under the ICB regime, optimal (interior) κ satisfies*

$$\frac{a}{b}\phi_1 \leq \kappa^{\mathrm{ICB}} \leq \frac{a}{b}\phi_2 \quad \left(\textit{given that} \quad \frac{a}{b}\phi_2 > 1 \right)$$

which also implies that a necessary condition for an interior solution under ICB is

$$a > b$$

Proof
See KTT conditions under ICB in Appendix B.4

□

A necessary condition for the centralised authority to delegate monetary policy to a more conservative and independent central bank ($\kappa^{\mathrm{ICB}} > 1$) is that the positive *ex ante* impact of a unit change in unanticipated inflation on output (a) should outweigh the negative impact of a unit change in distortionary taxation on output (b). The intuition behind this result is as follows. When monetary policy is set independently of budgetary considerations ($\lambda_2 = 0$ in the central's bank objective), the government is the only authority that still cares about the positive impact of seigniorage on government expenditures and thus it may find the independent central bank 'too' conservative *ex ante*. Hence, for an optimal $\kappa^{\mathrm{ICB}} > 1$, it should at least hold that the time-inconsistent behaviour of the central bank can boost the economy by more than the tax distortions reduce it. As in the case of DMC, a, b, ϕ_1 play a significant role in determining the degree of conservatism and hence the size of the monetary reform.

When $a\phi_1 < b$, the government would want to delegate an independent central bank that is *less* inflation averse than itself. Given that this is not possible, the degree of inflation aversion of the independent central bank is equalised to the government's ($\kappa^{\mathrm{ICB}} = 1$) and debt has an additional effect. The government has the incentive to accumulate debt strategically[21] so as to 'force' an expansionary monetary policy in period two. This effect moves to the same direction as the intertemporal anti-corruption, enhancing the accumulation of debt and the effort to fight corruption. As will be shown in Section 4.3, such a scenario may result in over-investment in fighting corruption relative to the commitment case.

[21] See Beetsma and Bovenberg (1997) and Dimakou (2006) for a more detailed discussion with regards to strategic accumulation of debt.

Finally, $f_1^{\max}$ can be supported as an optimal choice under ICB if

$$\theta < \theta_L^{\text{ICB}} = \frac{\kappa\lambda_2\gamma \text{FR}\widetilde{K}^m\tilde{k}^m}{\left(\frac{1-\phi_1^2}{\gamma}\right)\left\{4\Delta_2^m V_2^m(1+\beta(1+\rho)^2\Delta^m) - (1-\phi_1^2)\kappa\lambda_2\widetilde{K}^m\tilde{k}^m\right\}}.$$

Comparing the two decentralisation regimes, it can be easily shown that:

Proposition 6. *If* $(\phi_2^{\text{ICB}} - \phi_1) < \frac{b}{a}$ *optimal* κ *under DMC will always be greater than optimal* κ *under ICB.*

Proof

Combining propositions 4 and 5, $\kappa^{\text{DMC}} > \kappa^{\text{ICB}}$, if and only if

$$1 + \frac{a}{b}\phi_1 > \frac{a}{b}\phi_2^{\text{ICB}} \Leftrightarrow (\phi_2^{\text{ICB}} - \phi_1) < \frac{b}{a}$$

□

Proposition 6 suggests that unless the investment in fiscal capacity under an independent central bank is very large, the optimal degree of conservatism of DMC will be greater. Indeed, a purely independent central bank is already too inflation averse from the fiscal authority's view, since it ignores completely budgetary issues when setting inflation. Therefore, we would expect the degree of conservatism to be greater under DMC than ICB.

4.2 'Strategic' Complementarity

In the previous section we presented a set of analytical results with regards to the optimal investment decisions under all regimes. Proposition 1 confirms the superiority of the commitment design in terms of fighting corruption, while proposition 2 establishes that the discretionary regime systematically under-invests in fiscal institutions (relative to commitment). The rest of the results (propositions 3-6) focus on the decentralised cases and the optimal delegation parameter, identifying important structural factors that influence the size of the monetary reform and providing some comparisons. We now discuss in more detail how the two investment decisions may interact with one another.

Within the decentalised schemes we can examine whether the two investment decisions exhibit 'strategic' complementarities in the spirit of Bulow, Geanakoplos, and Klemperer (1985). Unlike the conventional ones, strategic substitutes or complements are defined by whether a more 'aggressive' strategy by one player lowers or raises the marginal payoff of another player. We use a 'modified' version of this idea to examine how the incentives to improve one institution are affected by the decision to improve the other. In our case, similar to Besley and Persson (2009), there is one player (government) and one utility function upon which the decisions to invest in improving monetary and/or fiscal institutions are based. Within this context, we look at whether the two investment decisions reinforce each other, relying on the supermodularity of the utility function.

If the two investment decisions exhibit strategic complementarities, then by totally differentiating the two first order conditions, it should hold for $j = \text{DMC}, \text{ICB}$:

$$\frac{\partial^2 U^{*,j}(f_1,\kappa)}{\partial f_1^2} df_1 + \frac{\partial^2 U^{*,j}(f_1,\kappa)}{\partial \kappa \partial f_1} d\kappa = 0 \Rightarrow \qquad \frac{df_1}{d\kappa} = -\frac{\partial^2 U^{*,j}(f_1,\kappa)/\partial \kappa \partial f_1}{\partial^2 U^{*,j}(f_1,\kappa)/\partial f_1^2} > 0 \tag{14}$$

$$\frac{\partial^2 U^{*,j}(f_1,\kappa)}{\partial \kappa^2} d\kappa + \frac{\partial^2 U^{*,j}(f_1,\kappa)}{\partial f_1 \partial \kappa} df_1 = 0 \Rightarrow \qquad \frac{d\kappa}{df_1} = -\frac{\partial^2 U^{*,j}(f_1,\kappa)/\partial f_1 \partial \kappa}{\partial^2 U^{*,j}(f_1,\kappa)/\partial \kappa^2} > 0 \tag{15}$$

Thus, an increase in fiscal capacity, raises the *marginal* utility of investing in monetary improvements and hence boosts the incentive to delegate a more conservative (and/or independent) central bank. Alike, delegation of a more inflation averse central bank boosts the demand for reduction in fiscal leakages, since with smaller seigniorage revenues, the need for a more efficient tax collection mechanism increases.

As we cannot obtain closed form solutions, we will be numerically checking the strategic complementarity among the investment decisions at the optimum points under different parameter values in Section 4.3. Notice that since the two cross-partial derivatives are equal (Young's Theorem) and at the optimum the direct second derivatives will be negative, the investment decisions are strategic complements whenever, $\frac{\partial^2 U^{*,j}(f_1,\kappa)}{\partial \kappa \partial f_1} = \frac{\partial^2 U^{*,j}(f_1,\kappa)}{\partial f_1 \partial \kappa} > 0$.

The complementarity property is of substantial interest, as it suggests that common interests in fiscal and monetary institutions are important in explaining their development and their determinants. Given that the two investment decisions are strategic complements, then results on monotone comparative statics can be facilitated. Let $U^{*,j}(f_1,\kappa,z), j = \text{DMC}, \text{ICB}$ represent the overall welfare function for a vector of relevant parameters z. Then, any factor in z that raises $\frac{\partial U^{*,j}}{\partial f_1}$ and $\frac{\partial U^{*,j}}{\partial \kappa}$ would raise optimal investment in both fiscal and monetary institutions, as the direct effects of changes in z on f_1, κ and the indirect ones (via the interaction of the investment decisions) move to the same direction.[22] Exploiting monotone comparative statics, together with the existence of complementarities, gives rise to the following proposition.

Proposition 7. *Other things being equal, investment in both monetary and fiscal institutions is enhanced when*

(a) the government's exogenous overall financial requirement, FR, is increased

(b) the unit cost for fighting corruption is decreased

under both decentralised regimes.

Proof

See Appendix B.6

□

[22]The total differential of the FOCs involves three differentials, dz, df_1 and $d\kappa$. The direct effects are: $\frac{\partial^2 U^{*,j}(f_1,\kappa;z)}{\partial z \partial f_1}, \frac{\partial^2 U^{*,j}(f_1,\kappa;z)}{\partial z \partial \kappa}$ and the indirect ones, $\frac{\partial^2 U^{*,j}(f_1,\kappa)}{\partial \kappa \partial f_1}, \frac{\partial^2 U^{*,j}(f_1,\kappa)}{\partial f_1 \partial \kappa}$.

This result suggests that a higher desired level of public goods provision (g^*) or a higher initial debt level (d_0) can enhance both investments. Since the importance of a better functioning tax system is greater, the demand for investment in fiscal capacity is increased. Although the delegation decision is not directly affected by changes in FR, the incentive to improve on monetary institutions is strengthened via the complementarity property. Similarly, when the unit cost coefficient is lower, the incentive to fight corruption increases, which in turn enhances the demand for a larger central bank reform.

4.3 Numerical Results

In addition to the analytical results discussed above, this section performs a set of comparative statics employing different numerical simulations for our model economy. First, we compare the optimal investment to fight corruption under all regimes and, second, we identify a set of structural factors that influence the decisions to investment on both economic institutions under the decentralised cases.

The parameters of the model are depicted in Table 1. Consistent with the literature, we set β to 0.96 which implies an annual interest rate of around 4%. The initial corruption level coefficient is let to vary within its full range, $0 < \phi_1 < 1$, and explore the impact of different initial institutional quality on optimal investment decisions.

Table 1: Parameters Values

Parameter		Range
λ_1	Government's weight on output gap relative to inflation	0.3 - 1.2
λ_2	Government's weight on government spending gap relative to inflation	0.4 - 2
β	Discount factor	0.96
ρ	Real interest rate	0.041
ϕ_1	Initial corruption level	0.15 -0.95
γ	Unit efficiency coefficient	0.7 - 1
θ	Unit cost of fighting corruption (as a share of non-distortionary output)	0.05 - 0.25
a	Measures the impact of unanticipated inflation on (log) output	0.8 - 3
b	Measures the degree of tax distortions on (log) output	0.5-1
g^*	Government spending target (as a share of output)	0.2 - 0.35
y_n	'Natural' level of output	
d_0	Initial debt level(as a share of output)	0.15 - 0.4
FR	Exogenous overall financial requirement	$(1+\rho)d_0 + g^* + \frac{g^*}{1+\rho}$

As discussed in Section 2, the derivation of the Phillips curve from a model as in Alesina and Tabellini (1987) implies that $a = b = \frac{\eta}{1-\eta}$, where η is the labour share in the production function. Our model relaxes this by setting $a \neq b$, which can allow for more complex derivations of these coefficients and try and match the numerical values proposed by a set of more recent studies[23]. Earlier studies commonly set $a = b = 1$. However, in the new-Keynesian framework a is proportionally related to the degree of nominal rigidities (usually sticky prices) and, together with the labour share, also depends on the elasticity of substitution among goods, the labour supply elasticity and the discount factor. On the other hand, the impact of distortionary taxes on output (b) should be expected to be smaller and is again described by labour market characteristics. For instance, Benigno and Woodford (2004) develop a general equilibrium new-Keynesian framework, in which both monetary (interest rates) and fiscal (taxes and debt) policies are studied in a setting with sticky prices and distortionary taxation. Consequently, the New-Keynesian Philips curve includes the negative impact of taxation, as in our case.

Due to the lack of empirical evidence different values for the cost and efficiency coefficients, θ and γ are used. A higher γ implies that anti-corruption effort is more efficient, and the government can improve fiscal capacity with more ease. In the same lines, a smaller unit cost coefficient can also lead to more effort in fighting corruption (see proposition 7). Thus, changes of the unit efficiency relative to the unit cost of fighting corruption, γ/θ, is of importance in determining the response of investment decisions. Note that the lower bound of the unit cost bellow which full investment in combating corruption takes place in each regime provides a guide in selecting values for θ.

With regard to the relative weights of the government's loss function, there is general consensus that λ_1, the weight on output gap deviations, should be smaller than one in the region of (0.1 - 0.5). This parameter range is observed in several studies that use or refer to the linear-quadratic approach to obtain the government loss function.[24] However, our model incorporates active monetary and fiscal policy, and the loss function includes an additional government spending gap, with weight λ_2. Indicative values for λ_2 are lacking, and when both monetary and fiscal policies are analysed, the appropriate value for λ_1 need not stay unchanged. Note that even when Benigno and Woodford (2004) incorporate fiscal policies in the New-Keynesian model, there is no government spending argument in their loss function, since individuals do not derive utility from public goods. Consequently, we examine various cases where individually and together λ_1 and λ_2 are less and greater than unity. For the targets in the government's objective function, y_n need not be parameterised, since we only focus in the output gap, $y - y_n$, and y_n is regime-invariant. The government spending target, g^*, is a part of the exogenous overall financial requirement of the government, FR and so is d_0. We set various values for both.

[23] See for example, Adam and Billi (2010), Benigno and Woodford (2004), Schmitt-Grohe and Uribe (2004).

[24] In Benigno and Woodford (2004) optimal λ_1 is close to 0. Tillmann (2008) sets $\lambda_1 = 0.25$ and Walsh (2003) varies it up until 0.5.

Our analysis includes three sets of comparative statics exercises. We firstly look at the conventional model with $a = b = 1$ and verify the investment decisions for different ratios of λ_1, λ_2 as well as different initial corruption levels. Secondly, we allow for a and b to be different, and finally we look at a calibration that closely resembles the New Keynesian models.

Example 1: $a = b = 1$ as in Alesina and Tabellini (1987)

We start off presenting our first specification where $a = b = 1$, while λ_1, λ_2 vary around 1, for different initial corruption parameters. Both λ_1, λ_2 are decreasing, but λ_2 gets relatively bigger than λ_1, as seen in Table 2.

Table 2: Specification 1: $a = b = 1$

	i	ii	iii		with		
λ_1	1.1	0.8	0.4	γ	0.75	θ	0.1
λ_2	1.4	1.2	0.8	β	0.96	ρ	0.04
λ_2/λ_1	1.27	1.5	2	g^*	0.3	d_0	0.25

Figure 2 depicts optimal anti-corruption efforts, delegation parameters and debt levels for each of the four regimes at different levels of initial bureaucratic corruption.[25] A higher initial corruption level (lower ϕ_1) increases the anti-corruption efforts, as the need for that intensifies, and the optimal debt level issued in all institutional settings. At the point were there is almost no corruption ($\phi_1 = 0.95$), there is full effort in eliminating future corruption for all regimes. For the DMC regime, as corruption worsens, the incentive to delegate a more conservative central bank decreases; the positive impact of inflation (seigniorage) on government's revenues is much appreciated when the formal tax system gets more inefficient. For the ICB regime, the optimal degree of conservatism bounds to zero. The independent central bank shares the same weight on output gap as the government.

[PUT Figure 2 HERE]

Figure 2: Effort, Delegation and Debt - Specification 1

(a) Optimal Effort (b) Optimal Delegation (c) Optimal Debt

Comparing the regimes at each given level of initial corruption, since the institutional design with an independent central bank obtains a boundary solution, optimal f_1^{ICB} is the greatest, surpassing even the SB one. Hence, as discussed in proposition 5, the ICB regime exhibits over-investment in fighting corruption and over-accumulation of debt (see Figure 2(c)). The government borrows more (relative to SB) in order to support the anti-corruption costs and also in an attempt to 'force' an expansionary monetary policy in period two (strategic accumulation of debt). The discretionary regime always under-invests in fighting corruption. Relative to SB, too much revenues

[25] We use the parameter values of the first column of Table 2. Similar findings are observed for the next two columns.

is collected in the form of inflation and too little in the form of taxation and debt (credibility effect of debt dominates), as discussed in proposition 2.

The delegation to a more conservative central bank (DMC) regime replicates the commitment (SB) quite well in terms of fighting corruption. As institutional quality improves, the two effort lines get more indistinguishable. The same applies for debt. In principal, higher initial corruption leads to more investment in reducing fiscal leakages (higher f_1), but less incentives towards an inflation averse central bank (lower κ). This result does not invalidate the strategic complementarity property, which is actually confirmed at the optimum. It is the dominant direct effects of changes in ϕ_1 that move the investment decisions to opposite directions. There is a notable exception; at very severe levels of corruption (too low ϕ_1), a further increase in corruption decreases optimal DMC effort (see Figure 2(a)).

Comparing across the changes in the relative weight on government spending with respect to the output gap, an increase in λ_2/λ_1, raises optimal anti-corruption efforts for all regimes (Figure 3). As λ_2/λ_1 increases, the government cares more for public spending, which is in turn limited by corruption. Thus, the demand to reduce tax leakages increases. For the DMC regime, we confirm a positive co-movement for both investment decisions.

[PUT Figure 3 HERE]

Figure 3: Optimal Efforts and Delegation - Specification 1

(a) Optimal Effort in SB and DIS (b) Optimal Effort in ICB

(c) Optimal Effort in DMC (d) Optimal Delegation in DMC

Example 2: $a \neq b$

In the second specification we focus on the impact of changes in a/b. We set $a > b$, and increase a such that $\frac{a}{b} = 1.36$, 2.5 and 3.88.

Table 3: Specification 2: $a > b$ - Changing a

λ_1	0.8	β	0.96 (ρ =0.04)
λ_2	1.2	g^*	0.3
θ	0.15	d_0	0.25
γ	0.75	b	0.6

The commitment outcome is unaffected by changes in a, since expectations are formed ex ante. For the rest of the regimes, higher is a, lower is the government's effort to tackle corruption in all three levels of corruption depicted in Table 4. Regarding the two investment decisions under the institutional designs where decentralisation of policies is allowed, we observe that they move to opposite directions, in spite of the positive interaction among the two decisions.[26] A higher impact of surprise inflation

[26] That is, despite the strategic complementarity property, the direct effects of changes in a on f_1 and κ dominate.

(higher a) on output, decreases the incentive to minimise fiscal leakages, but increases the incentive to delegate a more conservative (and/or independent) central bank. As a increases, the time-inconsistent behaviour of the monetary authority has a bigger positive impact in boosting output, hence the government can delegate a more conservative central bank and still gain from the boost of the economy's output. This was explicitly shown in propositions 4 and 5.

Table 4: Changes in a/b and ϕ_1 - Specification 2

		SB - Effort					DIS - Effort		
			a					a	
		0.8181	1.5	2.333			0.8181	1.5	2.333
	0.35	0.6303	0.6303	0.6303		0.35	0.5333	0.4238	0.3145
ϕ_1	0.55	0.5317	0.5317	0.5317	ϕ_1	0.55	0.4518	0.3567	0.2600
	0.75	0.4297	0.4297	0.4297		0.75	0.3673	0.2878	0.2057
		DMC - Effort					DMC - Delegation		
			a					a	
		0.8181	1.5	2.333			0.8181	1.5	2.333
	0.35	0.6150	0.6020	0.5990		0.35	1.7700	2.3700	3.1810
ϕ_1	0.55	0.5200	0.5190	0.5110	ϕ_1	0.55	1.9200	2.7220	3.6200
	0.75	0.4260	0.4210	0.4210		0.75	2.1700	3.0600	4.2300
		ICB - Effort					ICB - Delegation		
			a					a	
		0.8181	1.5	2.333			0.8181	1.5	2.333
	0.35	0.6418	0.5710	0.5710		0.35	1	1.4010	2.1790
ϕ_1	0.55	0.5145	0.5020	0.5020	ϕ_1	0.55	1	1.7200	2.6700
	0.75	0.4190	0.4180	0.4180		0.75	1.1500	2.1040	3.2800

On the other hand, the negative relation between a and anti-corruption effort can be understood as follows. The higher the impact of surprise inflation on output, the more inflation is used (relative to taxation) in raising government revenues. Thus, the negative impact that corruption has due to tax leakages is not considered as significant and the demand for anti-corruption efforts decreases. Note that similar results would obtain if the nature of taxation were less distortionary (lower b), although this change would also affect the commitment regime. Corruption is harmful because it deprives the state from the required tax revenues to achieve its desired government spending. To deliver a given level of public goods, the government would have to tax more or inflate more. However, taxes distort the labour market and reduce output and seigniorage also impacts overall utility negatively. When the distortionary nature of taxation is low or the positive effect of inflation on output is high, the impact of corruption is not viewed as harmful.

As before, a better initial institutional quality (higher ϕ_1) implies less effort in fighting corruption, since corruption incidences are fewer, for all regimes examined. In addition, for the DMC and ICB cases, higher ϕ_1 translates into more central bank conservatism. Strategic complementarities among the two investment decisions at the optimum levels attained at each different a, ϕ_1 are numerically confirmed.

Example 3: Matching the New-Keynesian calibrations

In the following specification we try to match some of Benigno and Woodford's (2004) calibrations more closely. We set the tax distortion coefficient equal to 0.45, and decrease λ_1 to 0.3. Although there is no direct comparison between our price-stickiness (fixed wages a period in advance) and the Calvo pricing scheme, $a = 0.81$ lies within their hypothesised values for the Philips curve slope coefficient. The initial debt level is increased to 40% of GDP. Finally, we set the unit efficiency relative to cost coefficient at ($\gamma/\theta = 0.8/0.2$), ensuring interior solutions are obtained for all regimes. We allow for ϕ_1 and λ_2 to vary and confirm our results remain robust.

Table 5: Specification 3 - Change ϕ_1 with $\lambda_2 = 0.4$

		Effort					Delegation	
		SB	*DIS*	*DMC*	*ICB*		*DMC*	*ICB*
	0.4	0.68879	0.65423	0.685	0.6825	0.4	2.38	1.244
ϕ_1	0.6	0.54131	0.51613	0.539	0.536	0.6	2.172	1.387
	0.8	0.40735	0.39036	0.4065	0.405	0.8	2.058	1.626

As in the previous specifications, a lower initial corruption level implies a higher investment in fighting fiscal leakages, and a lower degree of conservatism (Table 5). Across regimes, the highest anti-corruption effort is achieved under the commitment outcome, followed by the decentralised regimes. The incentives to fight corruption are the lowest when policies are set discretionary. As regards to increases in λ_2, the

Table 6: Specification 3 - Changes in ϕ_1 and λ_2

		Effort					Delegation	
		SB	DIS	DMC	ICB		DMC	ICB
	0.3	0.51193	0.4853	0.51	0.5065	0.3	2.357	1.37
λ_2	0.4	0.54131	0.51613	0.539	0.536	0.4	2.38	1.387
	0.6	0.57357	0.55024	0.5715	0.5685	0.6	2.39	1.406

more the government cares about government spending, the higher is investment in fiscal institutions. This positive impact is observed in all regimes. With respect to the delegation parameters, as λ_2 increases, the optimal degree of conservatism also rises for both regimes with decentralised economic policies, albeit moderately. Despite the fact that the government cares more about government spending, it chooses to delegate a more conservative central bank. The intuition behind this result lies on the importance of strategic complementarities. As the government exhibits effort in improving its tax collection mechanism, it will enjoy a more efficient tax system and higher tax revenues. The improved outcome in the use of the formal tax collection avenue is reflected in the government's decision to delegate a more conservative central bank, since the benefits from a more inflation averse central bank are enhanced.

Summing up, with the use of different numerical simulations we have compared the investment decisions across the four institutional settings and verified the superiority of the commitment regime in terms of anti-corruption efforts[27]. The discretionary setting under-invests in fighting corruption, while decentralisation is replicating the commitment outcome closely. A set of factors influence the joint determination of investment in economic institutions under the decentralised regimes. We found that a higher overall financial requirement, higher weight on government spending relative to output gap and lower anti-corruption cost enhance the investment in both economic institutions. More initial corruption and a higher a/b ratio move the investment decisions to opposite directions, while strategic complementarities are always confirmed.

5 Conclusion

We develop a two period game theoretic model in which the fiscal and monetary authorities interact in the determination of their policy decisions and in addition the fiscal authority can set two investment decisions. It can reduce fiscal leakages by fighting bureaucratic corruption, and ameliorate the adverse consequences of discretionary monetary policy by delegating the later to a more conservative central bank. Within this framework of endogenous anti-corruption, four institutional designs are analysed. The second best (SB) and discretionary (DIS) institutional designs consist of a centralised authority, hence only investments in improving the fiscal institutions take place. Decentralisation of policies becomes an institutional characteristic in the last two designs. Following Rogoff (1985), the DMC regime allows for an optimally delegated more conservative central bank. Finally, cutting off budgetary considerations for the monetary policy setting, we can analyse the delegation of a purely independent and more conservative central bank (ICB). This paper focuses on the comparative statics of (i) the incentives to fight corruption under the above four settings and (ii) the interactions among the two investment decisions within the decentralised institutional designs. Preliminary empirical evidence shows that there is a positive correlation between those two reforms which suggests that analysing their interaction and determinants in more detail is of great importance.

We find that the commitment setting is more conductive to fighting corruption and to this end borrowing plays a positive role, as it can be used to finance the anti-corruption programme and reallocate taxation to period two. The discretionary regime under-invests in fighting corruption relative to the second best. The inflationary bias alleviates the negative impact of corruption, and discretionary debt policy is used to improve second period credibility rather than finance the cost of anti-corruption effort. When policy decentralisation is viable both investment decisions are improved relative to the discretionary regime. First, we verify that the discretionary setting is never optimal ex post; the optimal degree of conservatism is always greater than zero. Second, the incentive to reduce fiscal leakages is higher under the DMC regime compared to discretion. With a purely independent central bank the direct credit

[27] With the exception of the case where an independent central bank with κ^{ICB} is obtained.

channel to the government is shut *ex ante*. Hence, the government will optimally reform to a more conservative and independent central bank under a more restrictive set of parameter values compared to DMC, but anti-corruption effort is always found to the higher than the discretionary one.

With regards to the delegation parameter alone, the higher the initial corruption level, the lower the *ex ante* impact of unanticipated inflation or the bigger the distortionary nature of taxation, the smaller the optimal monetary reform will be for both delegation regimes. Furthermore, under ICB, the chances of a boundary solution are increased, which may result in over-investment in fighting corruption (surpassing even the SB) and over-accumulation of debt (strategic use of debt). These findings suggest that the favourability of central bank reforms should be analysed in conjunction with the stance of fiscal institutions, such as the (in)efficiency of the tax collection system and the distortions taxation may cause in the labour maket. They also suggest that tackling issues with weak fiscal institutions may be a pre-requisite for delegating monetary policy.

Within the settings where the fiscal authority is allowed to invest in improving both the monetary and fiscal institutions, we find evidence of important common interests among the two investments. In all our numerical simulations, we can confirm that the two investment decisions exhibit 'strategic' complementarities under the DMC and ICB regimes, given that interior solutions are obtained for the latter. That is, improving one institution, increases the marginal utility with respect to the other investment, and hence the incentive to invest more in the other institution. Furthermore, we identify a set of determinants that impact on the government's decisions to improve economic institutions, which boil down to the structure and intensity of corruption, the policymaker's government spending target, the amount of distortions taxation causes and the policymaker's preferences in relation to its conflicting goals. Consequently, anti-corruption efforts should be viewed and analysed more closely in relation to both the structural stance of the economy in question and the process of other on-going reforms. Finally, the existence or not of other institutional and structural constraints (e.g. credit constraints or fiscal discipline rules) could prove very relevant, as such constraints may potentially restrict the incentive of the one reform with negative spill overs on the other.

A Appendix: Optimal Policies

Table A.1: Optimal Policies: Second Best, Discretion and Decentralisation

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$$\underline{SB}: \quad d_1^{\mathrm{SB}}(f_1) = \frac{[(1+\rho)d_0 + g^* + C(f_1) - g^*] + [1-\beta(1+\rho)D]\,g^*}{1+\beta(1+\rho)^2 D}$$

$$\tau_1^{\mathrm{SB}}(f_1) = \frac{\phi_1\lambda_2}{D_1}\frac{\beta(1+\rho)^2 D[\mathrm{FR}+C(f_1)]}{(1+\beta(1+\rho)^2 D)}; \qquad \tau_2^{\mathrm{SB}}(f_1) = \frac{\phi_2\lambda_2}{D_2}\frac{(1+\rho)[\mathrm{FR}+C(f_1)]}{(1+\beta(1+\rho)^2 D)}$$

$$\pi_1^{\mathrm{SB}}(f_1) = \frac{b^2\lambda_1\lambda_2}{D_1}\frac{\beta(1+\rho)^2 D[\mathrm{FR}+C(f_1)]}{(1+\beta(1+\rho)^2 D)}; \quad \pi_2^{\mathrm{SB}}(f_1) = \frac{b^2\lambda_1\lambda_2}{D_2}\frac{(1+\rho)[\mathrm{FR}+C(f_1)]}{(1+\beta(1+\rho)^2 D)}$$

$$U^{*,\mathrm{SB}}(f_1) = u_1^{*,SB} + \beta u_2^{*,SB} = -\frac{1}{2}\frac{b^2\lambda_1\lambda_2}{D_2}\frac{\beta(1+\rho)^2[\mathrm{FR}+C(f_1)]^2}{1+\beta(1+\rho)^2 D}$$

where $FR = (1+\rho)d_0 + g^* + \dfrac{g^*}{1+\rho} = F_0 + \dfrac{g^*}{1+\rho}$ (overall financial requirement)

$$D_1 = b^2\lambda_1\lambda_2 + \phi_1^2\lambda_2 + b^2\lambda_1 \qquad D = \tfrac{D_1}{D_2} \le 1 \forall f_1 \ge 0$$
$$D_2 = b^2\lambda_1\lambda_2 + \phi_2^2\lambda_2 + b^2\lambda_1$$

$$\underline{DIS}: \quad d_1^{\mathrm{DIS}}(f_1) = \frac{[(1+\rho)d_0 + g^* + C(f_1) - g^*] - [1-\beta(1+\rho)\Omega]\,g^*}{1+\beta(1+\rho)^2\Omega}$$

$$\tau_1^{\mathrm{DIS}}(f_1) = \frac{\phi_1\lambda_2}{\Omega_1}\frac{\beta(1+\rho)^2\Omega[\mathrm{FR}+C(f_1)]}{(1+\beta(1+\rho)^2\Omega)}; \quad \pi_1^{\mathrm{DIS}}(f_1) = \frac{b\lambda_1\lambda_2(b+a\phi_1)}{\Omega_1}\frac{\beta(1+\rho)^2\Omega[\mathrm{FR}+C(f_1)]}{(1+\beta(1+\rho)^2\Omega)}$$

$$\tau_2^{\mathrm{DIS}}(f_1) = \frac{\phi_2\lambda_2}{\Omega_2}\frac{(1+\rho)[\mathrm{FR}+C(f_1)]}{(1+\beta(1+\rho)^2\Omega)}; \qquad \pi_2^{\mathrm{DIS}}(f_1) = \frac{b\lambda_1\lambda_2(b+a\phi_2)}{\Omega_2}\frac{(1+\rho)[\mathrm{FR}+C(f_1)]}{(1+\beta(1+\rho)^2\Omega)}$$

$$U^{*,\mathrm{DIS}}(f_1;\mathfrak{z}) = u_1^{*,DIS} + \beta u_2^{*,DIS} = -\frac{1}{2}\frac{b^2\lambda_1\lambda_2 R_2}{\Omega_2^2}\frac{\beta(1+\rho)^2[\mathrm{FR}+C(f_1)]^2(1+\beta(1+\rho)^2\Omega_R)}{(1+\beta(1+\rho)^2\Omega)^2}$$

where $\Omega_1 = b\lambda_1\lambda_2(b+a\phi_1) + \phi_1^2\lambda_2 + b^2\lambda_1 \qquad \Omega_2 = b\lambda_1\lambda_2(b+a\phi_2) + \phi_2^2\lambda_2 + b^2\lambda_1$

$R_1 = \lambda_1\lambda_2(b+a\phi_1)^2 + \phi_1^2\lambda_2 + b^2\lambda_1 \qquad R_2 = \lambda_1\lambda_2(b+a\phi_2)^2 + \phi_2^2\lambda_2 + b^2\lambda_1$

$\Omega = \frac{\Omega_1 R_2}{\Omega_2^2}, \quad \Omega_R = \frac{R_1 R_2}{\Omega_2^2}$

$$\underline{DMC}: \quad d_1^{\mathrm{DMC}}(f_1,\kappa) = \frac{[(1+\rho)d_0 + g^* + C(f_1) - g^*] + [1-\beta(1+\rho)\Gamma]\,g^*}{1+\beta(1+\rho)^2\Gamma}$$

$$\tau_1^{\mathrm{DMC}}(f_1,\kappa) = \frac{\kappa\phi_1\lambda_2}{\Gamma_1}\frac{\beta(1+\rho)^2\Gamma[\mathrm{FR}+C(f_1)]}{(1+\beta(1+\rho)^2\Gamma)}; \quad \pi_1^{\mathrm{DMC}}(f_1,\kappa) = \frac{b\lambda_1\lambda_2(b+a\phi_1)}{\Gamma_1}\frac{\beta(1+\rho)^2\Gamma[\mathrm{FR}+C(f_1)]}{(1+\beta(1+\rho)^2\Gamma)}$$

$$\tau_2^{\mathrm{DMC}}(f_1,\kappa) = \frac{\kappa\phi_2\lambda_2}{\Gamma_2}\frac{(1+\rho)[\mathrm{FR}+C(f_1)]}{(1+\beta(1+\rho)^2\Gamma)}; \qquad \pi_2^{\mathrm{DMC}}(f_1,\kappa) = \frac{b\lambda_1\lambda_2(b+a\phi_2)}{\Gamma_2}\frac{(1+\rho)[\mathrm{FR}+C(f_1)]}{(1+\beta(1+\rho)^2\Gamma)}$$

$$U^{*,\mathrm{DMC}}(f_1,\kappa;\mathfrak{z}) = u_1^{*,DMC} + \beta u_2^{*,DMC} = -\frac{1}{2}\frac{b^2\lambda_1\lambda_2 C_2}{\Gamma_2^2}\frac{\beta(1+\rho)^2[\mathrm{FR}+C(f_1)]^2(1+\beta(1+\rho)^2\Gamma_C)}{(1+\beta(1+\rho)^2\Gamma)^2}$$

where $\Gamma_1 = b\lambda_1\lambda_2(b+a\phi_1) + \kappa(\phi_1^2\lambda_2 + b^2\lambda_1) \qquad C_1 = \lambda_1\lambda_2(b+a\phi_1)^2 + \kappa^2(\phi_1^2\lambda_2 + b^2\lambda_1)$

$\Gamma_2 = b\lambda_1\lambda_2(b+a\phi_2) + \kappa(\phi_2^2\lambda_2 + b^2\lambda_1) \qquad C_2 = \lambda_1\lambda_2(b+a\phi_2)^2 + \kappa^2(\phi_2^2\lambda_2 + b^2\lambda_1)$

$\Gamma = \frac{\Gamma_1 C_2}{\kappa\Gamma_2^2}; \quad \Gamma_C = \frac{C_1 C_2}{\kappa\Gamma_2^2}$

$$\underline{ICB}: \quad d_1^{\mathrm{ICB}}(f_1,\kappa) = \frac{[(1+\rho)d_0 + g^* + C(f_1) - g^*] + [1-\beta(1+\rho)\Delta]\,g^*}{1+\beta(1+\rho)^2\Delta}$$

$$\tau_1^{\mathrm{ICB}}(f_1,\kappa) = \frac{\kappa\phi_1\lambda_2}{\Delta_1}\frac{\beta(1+\rho)^2\Delta[\mathrm{FR}+C(f_1)]}{(1+\beta(1+\rho)^2\Delta)}; \quad \pi_1^{\mathrm{ICB}}(f_1\,\kappa) = \frac{b\lambda_1\lambda_2(b+a\phi_1)}{\Delta_1}\frac{\beta(1+\rho)^2\Delta[\mathrm{FR}+C(f_1)]}{(1+\beta(1+\rho)^2\Delta)}$$

$$\tau_2^{\mathrm{ICB}}(f_1,\kappa) = \frac{\kappa\phi_2\lambda_2}{\Delta_2}\frac{(1+\rho)[\mathrm{FR}+C(f_1)]}{(1+\beta(1+\rho)^2\Delta)}; \qquad \pi_2^{\mathrm{ICB}}(f_1,\kappa) = \frac{b\lambda_1\lambda_2(b+a\phi_2)}{\Delta_2}\frac{(1+\rho)[\mathrm{FR}+C(f_1)]}{(1+\beta(1+\rho)^2\Delta)}$$

$$U^{*,\mathrm{ICB}}(f_1,\kappa;\mathfrak{z}) = u_1^{*,ICB} + \beta u_2^{*,ICB} = -\frac{1}{2}\frac{b^2\lambda_1\lambda_2 V_2}{\Delta_2^2}\frac{\beta(1+\rho)^2[\mathrm{FR}+C(f_1)]^2(1+\beta(1+\rho)^2\Delta_V)}{(1+\beta(1+\rho)^2\Delta)^2}$$

where $\Delta_1 = ab\lambda_1\lambda_2\phi_1 + \kappa(\phi_1^2\lambda_2 + b^2\lambda_1) \qquad V_1 = a^2\lambda_1\lambda_2\phi_1^2 + \kappa^2(\phi_1^2\lambda_2 + b^2\lambda_1)$

$\Delta_2 = ab\lambda_1\lambda_2\phi_2 + \kappa(\phi_2^2\lambda_2 + b^2\lambda_1) \qquad V_2 = a^2\lambda_1\lambda_2\phi_2^2 + \kappa^2(\phi_2^2\lambda_2 + b^2\lambda_1)$

$\Delta = \frac{\Delta_1 V_2}{\kappa\Delta_2^2}; \quad \Delta_V = \frac{V_1 V_2}{\kappa\Delta_2^2}$

B Optimal investment decisions

B.1 Optimal Investment Decisions - Second Best

The second best maximisation problem for f_1 is,

$$\max_{f_1} U^{*,\mathrm{SB}}(f_1;\mathfrak{z}) \quad \text{s.t.} \quad 0 \leq f_1 \leq f_1^{\max}$$

$$\max_{f_1} L^{\mathrm{SB}} = U^{*,\mathrm{SB}}(f_1;\mathfrak{z}) + h_{f_1}^{\mathrm{sb}}(f_1^{max} - f_1)$$

$$L_{f_1}^{\mathrm{SB}} = \frac{\partial L^{\mathrm{SB}}}{\partial f_1} = \frac{dU^{*,\mathrm{SB}}}{df_1} - h_{f_1}^{\mathrm{sb}} \leq 0, \quad f_1 \geq 0 \quad \text{and} \quad f_1 L_{f_1} = 0$$

$$L_{h_{f_1}^{\mathrm{sb}}}^{\mathrm{SB}} = \frac{\partial L^{\mathrm{SB}}}{\partial h_{f_1}^{\mathrm{sb}}} = f_1^{\max} - f_1 \geq 0\ , \quad h_{f_1}^{\mathrm{sb}} \geq 0 \quad \text{and} \quad h_{f_1}^{\mathrm{sb}} L_{h_{f_1}^{\mathrm{sb}}}^{\mathrm{SB}} = 0$$

where

$$\frac{dU^{*,\mathrm{SB}}}{df_1} = \mathrm{FOC}_{f_1}^{\mathrm{SB}} = \mathrm{MULT}_{\mathrm{SB}} \left\{ -C'(f_1) + \frac{\lambda_2 \phi_2 \phi_2' [\mathrm{FR} + C(f_1)]}{D_2(1+\beta(1+\rho)^2 D)} \right\}$$

$$\mathrm{MULT}_{\mathrm{SB}} = \frac{b^2 \lambda_1 \lambda_2 \beta (1+\rho)^2 [\mathrm{FR} + C(f_1)]}{D_2(1+\beta(1+\rho)^2 D)} > 0$$

$$D = \frac{D_1}{D_2}, \quad \text{with } D_1, D_2 \text{ as defined in Appendix A.}$$

According to the KKT conditions:

a. Assume $f_1 = 0$. Then, $h_{f_1}^{\mathrm{sb}} = 0$ and $L_{h_{f_1}^{\mathrm{sb}}}^{\mathrm{SB}} > 0$. Thus, it should hold that $L_{f_1}^{\mathrm{SB}} = \mathrm{FOC}_{f_1}^{\mathrm{SB}} \leq 0$. However, for $f_1 = 0$, the first term within the brackets of $\mathrm{FOC}_{f_1}^{\mathrm{SB}}$ is zero ($C'(0) = 0$), though the second term is strictly positive, given that $\phi_2' > 0$. Thus, $\mathrm{FOC}_{f_1}^{\mathrm{SB}} > 0$ and $f_1 = 0$ is never optimal. This provides the proof for Proposition 1.

b. Assume $f_1 = f_1^{\max}$. Then, $L_{h_{f_1}^{\mathrm{sb}}}^{\mathrm{SB}} = 0$ and $h_{f_1}^{\mathrm{sb}} \geq 0$, which implies,

$$L_{f_1}^{\mathrm{SB}} = \mathrm{FOC}_{f_1}^{\mathrm{SB}} - h_{f_1}^{\mathrm{sb}} = 0 \Rightarrow \mathrm{FOC}_{f_1}^{\mathrm{SB}} \geq 0$$

Using the functional forms for the effort and cost functions, there exists a lower value for the unit cost coefficient of fighting corruption, called θ_L^{SB}, that makes $\mathrm{FOC}_{f_1}^{\mathrm{SB}}|_{f_1 = f_1^{\max}} = 0$. For all values below θ_L^{SB}, $\mathrm{FOC}_{f_1}^{\mathrm{SB}}$ is positive and $f_1^{\max}$ corresponds to the boundary solution of the second best institutional design.

Given the functions assumed in (6) and (7) we can actually obtain an analytical solution for the interior optimal f_1 in the SB. This is,

$$f_1^{\mathrm{SB}} = \frac{2\theta(1+\beta(1+\rho)^2)D_1 \pm \theta^{1/2}[4\theta(1+\beta(1+\rho)^2)^2 D_1^2 + 3\lambda_2^2\gamma^2\mathrm{FR}]^{1/2}}{-3\lambda_2\gamma\theta}.$$

We can verify the uniqueness of this positive solution, and also show that:

$$\frac{\partial f_1^{\text{SB}}}{\partial \theta} < 0; \qquad \frac{\partial f_1^{\text{SB}}}{\partial \gamma} > 0; \qquad \frac{\partial f_1^{\text{SB}}}{\partial \lambda_1} > 0$$
$$\frac{\partial f_1^{\text{SB}}}{\partial \text{FR}} > 0; \qquad \frac{\partial f_1^{\text{SB}}}{\partial \phi_1} < 0; \qquad \frac{\partial f_1^{\text{SB}}}{\partial \lambda_2} > 0$$

Therefore, under the second best institutional design, a lower unit cost coefficient, a higher efficiency coefficient, a higher financial requirement, a higher initial corruption level, a higher relative weight on government spending, and a lower relative weight on output increase the optimal level of effort in fighting corruption.

B.2 Optimal Investment Decisions - Discretion

The maximisation problem for the anti-corruption investment under the discretionary regime is:

$$\max_{f_1} U^{*,\text{DIS}}(f_1; \mathfrak{z}) \quad \text{s.t.} \quad 0 \leq f_1 \leq f_1^{\max}$$
$$L^{\text{DIS}} = U^{*,\text{DIS}}(f_1; \mathfrak{z}) + h_{f_1}^{\text{dis}}(f_1^{\max} - f_1)$$
$$L_{f_1}^{\text{DIS}} = \frac{\partial L^{\text{DIS}}}{\partial f_1} = \frac{\partial U^{*,\text{DIS}}(f_1; \mathfrak{z})}{\partial f_1} - h_{f_1}^{\text{dis}} \leq 0, \quad f_1 \geq 0 \quad \text{and} \quad f_1 L_{f_1}^{\text{DIS}} = 0$$
$$L_{h_{f_1}^{\text{dis}}}^{\text{DIS}} = \frac{\partial L^{\text{DIS}}}{\partial h_{f_1}^{\text{dis}}} = f_1^{\max} - f_1 \geq 0, \quad h_{f_1}^{\text{dis}} \geq 0 \quad \text{and} \quad h_{f_1}^{\text{dis}} L_{h_{f_1}^{\text{dis}}}^{\text{DIS}} = 0$$

where

$$\frac{dU^{*,\text{DIS}}(f_1; \mathfrak{z})}{df_1} = \text{FOC}_{f_1}^{\text{DIS}} = \text{MULT}_{\text{DIS}} \left\{ -C'(f_1)R_2 + \frac{\lambda_2 \phi_2 \phi_2' [\text{FR} + C(f_1)] \widetilde{S} \tilde{s}}{(1 + \beta(1+\rho)^2 \Omega) \Omega_2} \right\}$$

$$\text{MULT}_{\text{DIS}} = \frac{b^2 \lambda_1 \lambda_2 \beta (1+\rho)^2 [\text{FR} + C(f_1)]}{\Omega_2^2 (1 + \beta(1+\rho)^2 \Omega)} \frac{1 + \beta(1+\rho)^2 \Omega_R}{(1 + \beta(1+\rho)^2 \Omega)} > 0$$
$$\tilde{s} = \frac{(1 + \beta(1+\rho)^2 \widetilde{\Omega})}{(1 + \beta(1+\rho)^2 \Omega_R)} > 1, \; \Omega = \frac{\Omega_1 R_2}{\Omega_2^2} > 0, \; \Omega_R = \frac{R_1 R_2}{\Omega_2^2} > 0, \; \widetilde{\Omega} = \Omega_R + \frac{a \phi_1 n_1 R_2}{\Omega_2^2} > \Omega_R$$

with $R_1, R_2, \Omega_1, \Omega_2$ as defined in Appendix A. $\widetilde{S}$ is responsible for the existence of an interior solution and is equal to $\widetilde{S} = R_2 + ab\lambda_1(\phi_2\lambda_2 - ab\lambda_1)$. This is a quadratic expression in ϕ_2, which if it has no real solutions, then it is always positive, otherwise, since its symmetry of axis corresponds to a negative ϕ_2, it will have only one possible positive solution for ϕ_2, which will correspond to the necessary condition for an interior solution. In the majority of the numerical exercises performed, $\widetilde{S}$ was positive.

The KKT imply:

a. Assume $f_1 = 0$. Then $L_{h_{f_1}^{\text{dis}}}^{\text{DIS}} > 0$ and $h_{f_1}^{\text{dis}} = 0$. Thus,

$$L_{f_1}^{\text{DIS}} = \frac{\partial U^{*,\text{DIS}}(f_1; \mathfrak{z})}{\partial f_1} \leq 0$$

- if $\widetilde{S} = 0$, then $\text{FOC}_{f_1}^{\text{DIS}} = 0$ and $f_1 = 0$ is the optimal boundary solution

- if $\widetilde{S} < 0$, then $L^{\text{DIS}}_{f_1} < 0$ and $f_1 = 0$ is the boundary solution
- if $\widetilde{S} > 0$, then $L^{\text{DIS}}_{f_1} > 0$ and $f_1 = 0$ cannot be the solution

b. Assume $f_1 = f_1^{\max}$. Then, $L^{\text{DIS}}_{h^{\text{dis}}_{f_1}} = 0$, $h^{\text{dis}}_{f_1} \geq 0$ and $f_1 > 0$. Thus, it should hold that

$$L^{\text{DIS}}_{f_1} = \text{FOC}^{\text{DIS}}_{f_1} - h^{\text{dis}}_{f_1} = 0 \Rightarrow \text{FOC}^{\text{DIS}}_{f_1} \geq 0$$

- if $\widetilde{S} < 0$, then $\text{FOC}^{\text{DIS}}_{f_1} < 0$, so $f_1^{\max}$ cannot be the solution
- if $\widetilde{S} = 0$, then $\text{FOC}^{\text{DIS}}_{f_1} < 0$, so $f_1^{\max}$ cannot be the solution
- if $\widetilde{S} > 0$, then $\text{FOC}^{\text{DIS}}_{f_1}$ - uncertain. There exists a unit cost lower bound, θ^{DIS}_L, that makes $\text{FOC}^{\text{DIS}}_{f_1} = 0$. For any value below that bound, $\text{FOC}^{\text{DIS}}_{f_1} > 0$ and $f_1^{\max}$ can be supported as the optimal (boundary) solution.

The KKT assure that, whenever $\widetilde{S} \leq 0$, the only solution to the discretionary problem is $f_1 = 0$. $f_1^{\max}$ can be a solution only if $\widetilde{S} > 0$ and the cost of fighting corruption is low enough, as given by the lower bound.

When calculating the lower bound cost coefficient below which $f_1^{\max}$ is always optimal, θ^{DIS}_L, will be positive only if,

$$\widetilde{S}^m > 0 \rightarrow \underline{\lambda_2} > \frac{b^2\lambda_1(a^2\lambda_1 - 1)}{1 + ab\lambda_1 + (b+a)^2\lambda_1} \quad \text{and} \quad 4R_2^m\Omega_2^m\tilde{H}^m > (1-\phi_1^2)\lambda_2\widetilde{S}^m\tilde{s}^m$$

B.3 Optimal Investment Decisions - Delegation to a more conservative central bank

$$\max_{f_1,\kappa} U^{*,\text{DMC}}(f_1,\kappa;\mathfrak{z}) \quad \text{s.t.} \quad 0 \leq f_1 \leq f_1^{\max}, \quad \kappa \geq 1$$

$$\begin{aligned}
\max_{f_1,\kappa} L^{\text{DMC}} &= U^{*,\text{DMC}}(f_1,\kappa;\mathfrak{z}) + h^{\text{dmc}}_{f_1}(f_1^{\max} - f_1) + h^{\text{dmc}}_{\kappa}(\kappa - 1)\\
L^{\text{DMC}}_{f_1} &= \frac{\partial L^{\text{DMC}}}{\partial f_1} = \frac{\partial U^{*,\text{DMC}}(f_1)}{\partial f_1} - h^{\text{dmc}}_{f_1} \leq 0, f_1 \geq 0 \quad \text{and} \quad f_1 L^{\text{DMC}}_{f_1} = 0\\
L^{\text{DMC}}_{\kappa} &= \frac{\partial L}{\partial \kappa} + h^{\text{dmc}}_{\kappa} = 0\\
L^{\text{DMC}}_{h^{\text{dmc}}_{f_1}} &= \frac{\partial L^{\text{DMC}}}{\partial h^{\text{DMC}}_{f_1}} = f_1^{\max} - f_1 \geq 0, h^{\text{dmc}}_{f_1} \geq 0 \quad \text{and} \quad h^{\text{dmc}}_{f_1} L^{\text{DMC}}_{h^{\text{dmc}}_{f_1}} = 0\\
L^{\text{DMC}}_{h^{\text{dmc}}_{\kappa}} &= \kappa - 1 \geq 0\,, h^{\text{dmc}}_{\kappa} \geq 0 \quad \text{and} \quad h^{\text{dmc}}_{\kappa} L^{\text{DMC}}_{h^{\text{dmc}}_{\kappa}} = 0
\end{aligned}$$

where

$$\begin{aligned}
\frac{\partial U^{*,\text{DMC}}}{\partial f_1} &= \text{FOC}^{DMC}_{f_1} = \text{MULT}_{\text{DMC}}\left\{-C'(f_1)C_2 + \frac{\kappa\lambda_2\phi_2'[\text{FR} + C(f_1)]\widetilde{Q}\,q}{(1+\beta(1+\rho)^2\Gamma)(1+\beta(1+\rho)^2\frac{\Gamma_C}{\kappa})\Gamma_2}\right\}\\
\frac{\partial U^{*,\text{DMC}}}{\partial \kappa} &= \text{FOC}^{DMC}_{\kappa} = -\text{mult}_{\text{DMC}}\left\{[b(\kappa-1) - a\phi_1]\beta(1+\rho)^2\frac{n_1C_2^2}{\kappa^3\Gamma_2}\widetilde{L}_{m_1} + [b(\kappa-1) - a\phi_2]m_2n_2\,q\right\}
\end{aligned}$$

$$\text{MULT}_{\text{DMC}} = \frac{b^2\lambda_1\lambda_2\beta(1+\rho)^2[\text{FR}+C(f_1)]}{\Gamma_2^2(1+\beta(1+\rho)^2\Gamma)}\frac{(1+\beta(1+\rho)^2\frac{\Gamma_C}{\kappa})}{(1+\beta(1+\rho)^2\Gamma)} > 0$$
$$\text{mult}_{\text{DMC}} = \frac{b^2\lambda_1\lambda_2\beta(1+\rho)^2[\text{FR}+C(f_1)]^2}{\Gamma_2^3(1+\beta(1+\rho)^2\Gamma)^3} > 0$$
$$\Gamma = \frac{\Gamma_1 C_2}{\kappa\Gamma_2^2} > 0,\ \Gamma_C = \frac{C_1C_2}{\kappa\Gamma_2^2} > 0,\ \widetilde{L}_{m_1} = 1+\beta(1+\rho)^2\frac{m_1C_2}{\Gamma_2^2} > 0,$$
$$m_1 = \phi_1^2\lambda_2 + b^2\lambda_1 > 0,\ n_1 = \lambda_1\lambda_2(b+a\phi_1) > 0$$
$$m_2 = \phi_2^2\lambda_2 + b^2\lambda_1 > 0,\ n_2 = \lambda_1\lambda_2(b+a\phi_2) > 0\ \forall f_1,\kappa$$

In the main text's equations (10), (11), $\mathcal{I}_1, \mathcal{I}_2$ and $\mathcal{I}_3$ represent the strictly positive terms for the domains of f_1, κ in the two first order conditions:

$$\mathcal{I}_1 = \frac{\kappa\lambda_2\phi_2'[\text{FR}+C(f_1)]}{(1+\beta(1+\rho)^2\Gamma)(1+\beta(1+\rho)^2\frac{\Gamma_C}{\kappa})\Gamma_2} > 0, \quad \mathcal{I}_2 = \beta(1+\rho)^2\frac{n_1C_2^2}{\kappa^3\Gamma_2}\widetilde{L}_{m_1} > 0 \quad \text{and} \quad \mathcal{I}_3 = m_2n_2 > 0$$

Also,
$$\widetilde{Q} = \phi_2C_2 + b\lambda_1[b(\kappa-1) - a\phi_2][ab\lambda_1 - \lambda_2\phi_2]$$
$$q = 1+\beta(1+\rho)^2\frac{\widetilde{\Gamma}}{\kappa}$$
$$\widetilde{\Gamma} = \frac{(C_1 - n_1[b(\kappa-1)-a\phi_1])C_2}{\kappa\Gamma_2^2}$$

The KKT conditions give rise to the following cases:

a. Assume $f_1 = 0$ and $\kappa = 1$

Then, $L^{\text{DMC}}_{h^{\text{dmc}}_{f_1}} > 0$ and $h^{\text{dmc}}_{f_1} = 0$. Hence,

$$L^{\text{DMC}}_{f_1} = \text{FOC}^{\text{DMC}}_{f_1} \leq 0$$

And, $L^{\text{DMC}}_{h^{\text{dmc}}_{\kappa}} = 0$, $h^{\text{dmc}}_{\kappa} \geq 0$. So,

$$L^{\text{DMC}}_{\kappa} = \text{FOC}^{\text{DMC}}_{\kappa} + h^{\text{dmc}}_{\kappa} = 0 \Rightarrow \text{FOC}^{\text{DMC}}_{\kappa} \leq 0$$

However, with $f_1 = 0$ and $\kappa = 1$,

$$b(\kappa-1) - a\phi_1 = b(\kappa-1) - a\phi_2 = -a\phi_1 < 0 \quad \text{and} \quad q > 0$$

Thus, $\text{FOC}^{\text{DMC}}_{\kappa} > 0$, which implies that this specification is impossible.

b. $f_1 = f_1^{\max}$ and $\kappa = 1$. In this case,

- $L^{\text{DMC}}_{h^{\text{dmc}}_{f_1}} = 0 \Rightarrow h^{\text{dmc}}_{f_1} \geq 0$
- $L^{\text{DMC}}_{h^{\text{dmc}}_{\kappa}} = 0 \Rightarrow h^{\text{dmc}}_{\kappa} \geq 0$
- $L^{\text{DMC}}_{f_1} = \text{FOC}^{\text{DMC}}_{f_1} - h^{\text{dmc}}_{f_1} = 0 \Rightarrow \text{FOC}^{\text{DMC}}_{f_1} \geq 0$
- $L^{\text{DMC}}_{\kappa} = \text{FOC}^{\text{DMC}}_{\kappa} + h^{\text{dmc}}_{\kappa} = 0 \Rightarrow \text{FOC}^{\text{DMC}}_{\kappa} \leq 0$

However, with $f_1 = f_1^{\max}$ and $\kappa = 1$

$$b(\kappa - 1) - a\phi_1 < 0,\ b(\kappa - 1) - a < 0 \quad \text{and} \quad q > 0$$

Although, $\text{FOC}_{f_1}^{\text{DMC}}$ could be positive (the sign of $\widetilde{Q}$ is uncertain), $\text{FOC}_{\kappa}^{\text{DMC}}$ is strictly positive. So, this case is also infeasible. Thus, both first order conditions are strictly positive, which implies that this specification is impossible.

c. For $0 < f_1 < f_1^{\max}$ and $\kappa = 1$, we have:

- $L_{h_{f_1}^{\text{dmc}}}^{\text{DMC}} > 0 \Rightarrow h_{f_1}^{\text{dmc}} = 0$
- $L_{h_{\kappa}^{\text{dmc}}}^{\text{DMC}} = 0 \Rightarrow h_{\kappa}^{\text{dmc}} \geq 0$
- $f_1 > 0 \Rightarrow L_{f_1}^{\text{DMC}} = \text{FOC}_{f_1}^{\text{DMC}} = 0$
- $L_{\kappa}^{\text{DMC}} = \text{FOC}_{\kappa}^{\text{DMC}} + h_{\kappa}^{\text{dmc}} = 0 \Rightarrow \text{FOC}_{\kappa}^{\text{DMC}} \leq 0$

Again, $b(\kappa - 1) - a\phi_1 = -a\phi_1 < 0, = b(\kappa - 1) - a\phi_2 = -a\phi_2 < 0, \quad q > 0, \quad \text{sign}[\widetilde{Q}] = \text{uncertain}$. Hence, though $\text{FOC}_{f_1}^{\text{DMC}}$ could satisfy the condition above, $\text{FOC}_{\kappa}^{\text{DMC}}$ is strictly positive, which makes this case impossible.

d. $f_1 = 0$ and $\kappa > 1$ implies:

- $L_{h_{f_1}^{\text{dmc}}}^{\text{DMC}} > 0 \Rightarrow h_{f_1}^{\text{dmc}} = 0$
- $f_1 = 0 \Rightarrow L_{f_1}^{\text{DMC}} = \text{FOC}_{f_1}^{\text{DMC}} \leq 0$
- $L_{h_{\kappa}^{\text{dmc}}}^{\text{DMC}} > 0 \Rightarrow h_{\kappa}^{\text{dmc}} = 0$
- $L_{\kappa}^{\text{DMC}} = \text{FOC}_{\kappa}^{\text{DMC}} = 0$

This case is possible, only if the parameters' specification satisfies:

$$b(\kappa - 1) - a\phi_1 > 0,\ q < 0 \quad \text{and} \quad \widetilde{Q} > 0$$

e. For $f_1 = f_1^{\max}$ and $\kappa > 1$

- $L_{h_{f_1}^{\text{dmc}}}^{\text{DMC}} = 0 \Rightarrow h_{f_1}^{\text{dmc}} \geq 0$
- $f_1 > 0 \Rightarrow L_{f_1}^{\text{DMC}} = \text{FOC}_{f_1}^{\text{DMC}} - h_{f_1}^{\text{dmc}} = 0 \Rightarrow \text{FOC}_{f_1}^{\text{DMC}} \geq 0$
- $L_{h_{\kappa}^{\text{dmc}}}^{\text{DMC}} > 0 \Rightarrow h_{\kappa}^{\text{dmc}} = 0$
- $L_{\kappa}^{\text{DMC}} = \text{FOC}_{\kappa}^{\text{DMC}} = 0$

This scenario is possible.

f. $0 < f_1 < f_1^{\max}$ and $\kappa > 1$ (interior solution)

An interior solution with respect to κ requires that

$$[b(\kappa - 1) - a\phi_1] > 0 \quad \text{AND} \quad [b(\kappa - 1) - a\phi_2]q < 0$$

which combined with the requirement for an interior solution with respect to f_1 (product $\widetilde{Q}q$ should be positive), gives rise to two set of scenarios:

$$[b(\kappa-1)-a\phi_1]>0 \quad \text{AND} \quad [b(\kappa-1)-a\phi_2]<0 \quad \text{and} \quad q>0 \quad \text{and thus} \quad \widetilde{Q}>0$$

or

$$[b(\kappa-1)-a\phi_1]>0 \quad \text{AND} \quad [b(\kappa-1)-a\phi_2]>0 \quad \text{and} \quad q<0 \quad \text{and thus} \quad \widetilde{Q}<0$$

Under these conditions, a pure interior solution can be obtained. The necessary conditions imply that optimal delegation parameter will be greater than

$$\kappa > 1+\frac{a}{b}\phi_1$$

The infeasibility of the first three cases, rules $\kappa = 1$ out as a possible solution and provides the proof for proposition 3. The requirements for an interior solution (case f.) lead to proposition 4.

B.4 Optimal Investment Decisions - Delegation to a more conservative and independent central bank

$$\begin{aligned}
\max f_1,\kappa L^{\text{ICB}} &= U^{*,\text{ICB}}(f_1,\kappa;\mathfrak{z})+h^{\text{icb}}_{f_1}(f_1^{\max}-f_1)+h^{\text{icb}}_{\kappa}(\kappa-1)\\
L^{\text{ICB}}_{f_1} &= \frac{\partial L^{\text{ICB}}}{\partial f_1}=\frac{\partial U^{*,\text{ICB}}(f_1,\kappa;\mathfrak{z})}{\partial f_1}-h^{\text{icb}}_{f_1}\le 0,\ f_1\ge 0 \quad \text{and} \quad f_1L^{\text{ICB}}_{f_1}=0\\
L^{\text{ICB}}_{\kappa} &= \frac{\partial L^{\text{ICB}}}{\partial \kappa}=\frac{\partial U^{*,\text{ICB}}(f_1,\kappa;\mathfrak{z})}{\partial \kappa}+h^{\text{icb}}_{\kappa}=0\\
L^{\text{ICB}}_{h^{\text{icb}}_{f_1}} &= \frac{\partial L^{\text{ICB}}}{\partial h^{\text{DMC}}_{f_1}}=f_1^{\max}-f_1\ge 0,\quad h^{\text{icb}}_{f_1}\ge 0 \quad \text{and} \quad h^{\text{icb}}_{f_1}L^{\text{ICB}}_{h^{\text{icb}}_{f_1}}=0\\
L^{\text{ICB}}_{h^{\text{icb}}_{\kappa}} &= \kappa-1\ge 0\,,\quad h^{\text{icb}}_{\kappa}\ge 0 \quad \text{and} \quad h^{\text{icb}}_{\kappa}L^{\text{ICB}}_{h^{\text{icb}}_{\kappa}}=0
\end{aligned}$$

where

$$\begin{aligned}
\frac{\partial U^{*,\text{ICB}}}{\partial f_1} &= \text{FOC}^{\text{ICB}}_{f_1}=\text{MULT}_{\text{ICB}}\left\{-C'(f_1)V_2+\frac{\kappa\lambda_2\phi_2'[\text{FR}+C(f_1)]}{\Delta_2(1+\beta(1+\rho)^2\Delta)\big(1+\beta(1+\rho)^2\frac{\Delta_V}{\kappa}\big)}\widetilde{K}\,k\right\}\\
\frac{\partial U^{*,\text{ICB}}}{\partial \kappa} &= \text{FOC}^{\text{ICB}}_{\kappa}=-\text{mult}_{\text{ICB}}\left\{[b\kappa-a\phi_1]\beta(1+\rho)^2\frac{w_1V_2^2}{\kappa^3\Delta_2}\widetilde{X}_{m_1}+[b\kappa-a\phi_2]m_2w_2k\right\}
\end{aligned}$$

$$\begin{aligned}
\text{MULT}_{\text{ICB}} &= \frac{b^2\lambda_1\lambda_2\beta(1+\rho)^2[\text{FR}+C(f_1)]}{\Delta_2^2(1+\beta(1+\rho)^2\Delta)}\frac{\big(1+\beta(1+\rho)^2\frac{\Delta_V}{\kappa}\big)}{(1+\beta(1+\rho)^2\Delta)}\\
\text{mult}_{\text{ICB}} &= \frac{b^2\lambda_1\lambda_2\beta(1+\rho)^2[\text{FR}+C(f_1)]^2}{\Delta_2^3\big(1+\beta(1+\rho)^2\Delta\big)^3}
\end{aligned}$$

$$\Delta = \frac{\Delta_1 V_2}{\kappa \Delta_2^2}, \quad \Delta_V = \frac{V_1 V_2}{\kappa \Delta_2^2}, \quad \widetilde{X}_{m_1} = 1 + \beta(1+\rho)^2 \frac{m_1 V_2}{\Delta_2^2}$$
$$w_1 = a\lambda_1\lambda_2\phi_1, \quad m_1 = \phi_1^2\lambda_2 + b^2\lambda_1$$
$$w_2 = a\lambda_1\lambda_2\phi_2, \quad m_2 = \phi_2^2\lambda_2 + b^2\lambda_1$$
$$\widetilde{K} = \phi_2 V_2 + ab^2\lambda_1^2(b\kappa - a\phi_2); \; k = 1 + \beta(1+\rho)^2 \frac{[V_1 - w_1(b\kappa - a\phi_1)]V_2}{\kappa^2 \Delta_2^2}$$

and $V_1, V_2, \Delta_1, \Delta_2$ as defined in Appendix A.

In the main text, $\mathcal{E}_1, \mathcal{E}_2, \mathcal{E}_3$ represent the positive parts of the FOCs under central bank independence,

$$\mathcal{E}_1 = \frac{\kappa\lambda_2\phi_2'[\text{FR} + C(f_1)]}{\Delta_2(1+\beta(1+\rho)^2\Delta)\left(1+\beta(1+\rho)^2\frac{\Delta_V}{\kappa}\right)}$$
$$\mathcal{E}_2 = \beta(1+\rho)^2 \frac{w_1 V_2^2}{\kappa^3 \Delta_2} \widetilde{X}_{m_1} \quad \text{and} \quad \mathcal{E}_3 = m_2 w_2$$

According to the KKT conditions, all the following cases are feasible:

a. $f_1 = 0$ and $\kappa = 1$
b. $f_1 = f_1^{\max}$ and $\kappa = 1$
c. $0 \leq f_1 \leq f_1^{\max}$ and $\kappa = 1$
d. $f_1 = 0$ and $\kappa > 1$
e. $f_1 = f_1^{\max}$ and $\kappa > 1$
f. $0 \leq f_1 \leq f_1^{\max}$ and $\kappa > 1$ (interior solution)

An interior solution for f_1 requires that

$$\begin{aligned} \widetilde{K}k > 0 \quad \Leftrightarrow \quad & \widetilde{K} > 0 \quad \text{and} \quad k > 0 \\ \text{or} \quad & \widetilde{K} < 0 \quad \text{and} \quad k < 0 \end{aligned}$$

and for κ

$$\text{(i)}\ [b\kappa - a\phi_1] < 0 \quad \text{and} \quad [b\kappa - a\phi_2]k > 0$$
$$\text{or}$$
$$\text{(ii)}\ [b\kappa - a\phi_1] > 0 \quad \text{and} \quad [b\kappa - a\phi_2]k < 0$$

Case (i) is infeasible and from case (ii), the possibility with $[b\kappa - a\phi_2] > 0, k < 0$ ia also ruled out as it contradicts with the requirements for an interior f_1. Therefore, an interior solution for both variables requires,

$$[b\kappa - a\phi_1] > 0 \quad \text{AND} \quad [b\kappa - a\phi_2] < 0 \quad \text{and} \quad k > 0, \quad \text{thus} \quad \widetilde{K} > 0$$

which implies that an interior optimal delegation parameter for the institutional design of ICB should satisfy:

$$\frac{a}{b}\phi_1 < \kappa < \frac{a}{b}\phi_2, \quad \text{given that} \quad \frac{a}{b}\phi_2 > 1$$

B.5 Proof of Proposition 2

First note that if $\widetilde{S} < 0$ or if $\widetilde{S} > 0$ but the denominator in θ_L^{DIS} is negative, the proposition always holds. Given that

$$\widetilde{S} > 0 \quad \text{and} \qquad 4R_2^m\Omega_2^m(1+\beta(1+\rho)^2\Omega^m) > (1-\phi_1)\lambda_2\widetilde{S}^m\tilde{s}^m$$

suffice to show that

$$\begin{aligned} &R_2^m\Omega_2^m(1+\beta(1+\rho)^2\Omega^m)(1+\beta(1+\rho)^2\Omega_R^m) \\ &\qquad > \widetilde{S}^m D_2^m(1+\beta(1+\rho)^2D^m)(1+\beta(1+\rho)^2\Omega_R^m+\beta(1+\rho)^2\Omega_{n_1}) \end{aligned}$$

Note that:

$$\begin{aligned} &R_2^m\Omega_2^m > \widetilde{S}^m D_2^m \\ &(1+\beta(1+\rho)^2\Omega^m) > (1+\beta(1+\rho)^2D^m) \\ &(1+\beta(1+\rho)^2\Omega_R^m) < (1+\beta(1+\rho)^2\Omega_R^m+\beta(1+\rho)^2\Omega_{n_1}) \end{aligned}$$

After a large amount of cumbersome algebra, a sufficient condition that ensures that the LHS is smaller than the RHS is $\frac{a}{b} < \frac{1}{\phi_1}$. Nonetheless, one would expect the proposition to hold for many parameter values that do not satisfy the sufficient condition.

B.6 Proof of Proposition 7

(a) For the DMC, totally differentiating the two first order conditions with respect to FR, f_1 and κ gives,

$$\begin{aligned} U_{f_1f_1}df_1^* + U_{\kappa f_1}d\kappa^* &= -U_{\text{FRf}_1}d\text{FR} \\ U_{f_1\kappa}df_1^* + U_{\kappa\kappa}d\kappa^* &= -U_{\text{FR}\kappa}d\text{FR} \end{aligned} \quad \Rightarrow \quad \begin{aligned} \frac{df_1^*}{d\text{FR}} &= \frac{U_{\text{FR}\kappa}U_{\kappa f_1} - U_{\text{FR}f_1}U_{\kappa\kappa}}{|J|} > 0 \\ \frac{d\kappa^*}{d\text{FR}} &= \frac{U_{\text{FR}f_1}U_{f_1\kappa} - U_{\text{FR}\kappa}U_{f_1f_1}}{|J|} > 0 \end{aligned}$$

since, evaluated at the optimum, we have

$$\begin{aligned} &U_{f_1\kappa} = U_{\kappa f_1} > 0 \quad \text{(provided } f_1, \kappa \text{ exhibit complementarities)} \\ &|J| = U_{f_1f_1}U_{\kappa\kappa} - (U_{f_1\kappa})^2 > 0,\ U_{f_1f_1} < 0,\ U_{\kappa\kappa} < 0 \quad \text{(provided we have a maximum)} \\ &U_{\text{FR}\kappa} = 0 \quad \text{and} \quad U_{\text{FRf}_1} > 0 \end{aligned}$$

Similarly for the ICB, we have,

- ◇ $U_{\text{FR}\kappa}^{*,\text{ICB}}|_{(\kappa^*, f_1^*)} = 0$
- ◇ $U_{\text{FR}f_1}^{*,\text{ICB}} = \text{MULT}_{f_1}^{\text{ICB}}\dfrac{\kappa\lambda_2\phi_2'\widetilde{K}\tilde{k}}{\Delta_2(1+\beta(1+\rho)^2\Delta)} > 0$
- ◇ a maximum satisfies : $U_{f_1f_1}^{*,\text{ICB}} < 0\,;\quad U_{\kappa\kappa}^{*,\text{ICB}} < 0 \quad \text{and} \quad |J| > 0$
- ◇ complementarity satisfies: $U_{f_1\kappa}^{*,\text{ICB}} = U_{\kappa f_1}^{*,\text{ICB}} > 0$

$$\text{Hence, } \frac{df_1^*}{d\text{FR}} = -\frac{U^{*,\text{ICB}}_{\text{FR}f_1} U^{*,\text{ICB}}_{\kappa\kappa}}{|J|} > 0 \quad \text{and} \quad \frac{d\kappa^*}{d\text{FR}} = \frac{U^{*,\text{ICB}}_{\kappa f_1} U^{*,\text{ICB}}_{\text{FR}f_1}}{|J|} > 0$$

(b) For the DMC regime, totally differentiating the two first order conditions gives:

$$\begin{aligned}
\frac{\partial^2 U^{*,\text{DMC}}}{\partial f_1^2} df_1^* + \frac{\partial(\partial U^{*,\text{DMC}})}{\partial\kappa\partial f_1} d\kappa^* + \frac{\partial(\partial U^{*,\text{DMC}})}{\partial\theta\partial f_1} d\theta &= 0 \\
\frac{\partial(\partial U^{*,\text{DMC}})}{\partial f_1\partial\kappa} df_1^* + \frac{\partial^2 U^{*,\text{DMC}}}{\partial\kappa^2} d\kappa^* + \frac{\partial(\partial U^{*,\text{DMC}})}{\partial\theta\partial\kappa} d\theta &= 0
\end{aligned}$$

or

$$\begin{aligned}
U_{f_1 f_1} df_1^* + U_{\kappa f_1} d\kappa^* &= -U_{\theta f_1} d\theta \\
U_{f_1 \kappa} df_1^* + U_{\kappa\kappa} d\kappa^* &= -U_{\theta\kappa} d\theta
\end{aligned}$$

Therefore,

$$\frac{df_1^*}{d\theta} = \frac{-U_{\theta f_1} U_{\kappa\kappa} + U_{\theta\kappa} U_{\kappa f_1}}{|J|} < 0 \quad \text{and} \quad \frac{d\kappa^*}{d\theta} = \frac{-U_{f_1 f_1} U_{\theta\kappa} + U_{f_1\kappa} U_{\theta f_1}}{|J|} < 0$$

since, evaluated at the optimum levels for f_1, κ, we have:

- ✓ $$\frac{d\text{FOC}^{\text{DMC}}_{f_1}}{d\theta} = U^{*,\text{DMC}}_{\theta f_1} = -\frac{f_1}{2\phi_2} \text{MULT}_{f_1} \big\{ 4\phi_2 C_2 \Gamma_2 (1+\beta(1+\rho)^2 \Gamma_C)(1+\beta(1+\rho)^2\Gamma) - \kappa\lambda_2\gamma f_1 \widetilde{Q} q \big\} < 0$$
- ✓ $$\frac{d\text{FOC}^{\text{DMC}}_{\kappa}}{d\theta} = U^{*,\text{DMC}}_{\theta\kappa} = 0$$
- ✓ $|J| = U^{*,\text{DMC}}_{f_1 f_1} U^{*,\text{DMC}}_{\kappa\kappa} - \left(U^{*,\text{DMC}}_{f_1\kappa}\right)^2 > 0$
- ✓ given that f_1, κ are 'strategic complements' $U^{*,\text{DMC}}_{f_1\kappa} = U^{*,\text{DMC}}_{\kappa f_1} > 0$

Similarly for the ICB regime.

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