Contract Incompleteness, Contractual Enforcement and Bureaucracies[1]

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This paper explains a frequent coexistence of deficient property rights and heavy bureaucracies. We suggest that in environments with insecure ownership bureaucracies substitute for enforceable contracts. We study irreversible investment in an asset, and model the property allocation as a game between a ruler and investors. Since the *ex ante* ownership allocation is not enforceable, an *ex post* share increase is optimal for the ruler. His share adjustment is costly; the heavier the bureaucratic machine the higher his cost. Bureaucracy improves investment incentives by reducing the wedge between the ruler's *ex ante* and *ex post* equilibrium shares.

> Economics as a separate science is unrealistic, and misleading if taken as a guide in practice. It is one element – a very important element, it is true – in a wider study, the science of power.
>
> Bertrand Russell

Introduction

Environments with incomplete or non-enforceable contracts distort property rights and result in underinvestment. The problem of underinvestment originates in the divergence of *ex ante* and *ex post* incentives to invest. In the absence of enforcement mechanisms, any *ex ante* contract is obsolete *ex post,* when investment is sunk. Such contracts are routinely renegotiated and the resulting investment level is lower than when contracts are enforceable. To improve investment incentives, economic agents employ a variety of commitment mechanisms to induce honoring of the *ex ante* contract. The reputation-based mechanisms have been studied most extensively.

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This paper suggests that in environments with insecure property rights the bureaucratic machine is another important commitment mechanism.[2] We argue that in such cases bureaucracies serve a specific role and act as a substitute for enforceable contracts.[3] We suggest that bureaucratic machinery introduces additional rigidities in *ex post* contract renegotiation and through that, curtails disincentives to invest caused by contract non-enforceability.

The proposed commitment mechanism addresses a particular question of investment inefficiency in cases where a contractual solution is infeasible. However, the mechanism can be viewed as a generic tool for modelling the principal-agent problem. Any situation formalized as a resource allocation where *ex ante* allocation is altered *ex post* at a cost, embeds a commitment conflict and could be modelled with the setup proposed below.

We study irreversible investment in an asset over which the property rights are unclear. We model the allocation of property rights as a game between a ruler and investors. Player ownership shares are determined by their relative bargaining powers, which the ruler could alter at some cost by using the bureaucratic machinery. The term ruler refers to any political arrangement ranging from a feudal lord in Medieval Europe to a head of government, city mayor or other elected or appointed authority.

First, the players sign an *ex ante* contract. The allocation of ownership rights specified by this contract is not enforceable. Then, the investors choose the investments according to their expectations of the *ex post* ownership allocation.

[2]The lengthy technology slowdown subsequent to the fall of the Roman Empire is explained by economic historians by the decay of state provisions, such as infrastructure and legal framework. McNeil [1986] in "History of Western Civilization" provides the following description of the collapse of the Roman Empire. "The landowners who had staffed the imperial bureaucracy, commanded the Roman armies, and dominated provincial municipalities were crushed down by the weight of taxation. ... Money taxes became steadily more difficult to collect; and levies in kind, extracted in accordance with no sort of law, came to form the principal support of the army and of the state. Tax collection amounted to a little more than organized robbery... The Senatorial Class of the second century was largely destroyed; and with it perished the civilian, constitutional, peculiarly Roman, conception of government."

[3]The analysis of other bureaucratic functions is beyond the scope of this paper.

After the investment is sunk, in the *ex post* subgame the ruler can modify the *ex ante* property rights allocation at the exogenous cost of compensating the bureaucracy for his ownership share increase. The marginal cost of his share adjustment increases with the magnitude of adjustment, reflecting the usual assumption of decreasing returns in production. Bureaucracy is passive and does not behave strategically to extract part of the surplus.[4] Wilson [1989] suggests that one of the reasons for bureaucratic rigidity relates to the organizational culture, which permits to minimize the conflict and simplify the management. Derthick [1990] considers how the Social Security Administration (SSA) coped with the tasks to administer Supplemental Security Income (SSI) and Disability Insurance (DI).

The administration of SSI requires the SSA to decide who is needy and of DI – who is disabled. Both tasks are in conflict with the initial SSA 'philosophy' and task to administer the retirement benefits, which went to everybody who paid taxes into Social Security and who reached a certain age. These new tasks were fundamentally different from the initial SSA 'philosophy' of Social Security (by which was meant the commitment to serving beneficiaries). Derthick showed that efforts to cope with these tasks nearly overwhelmed the agency. SSA experienced a managerial nightmare and it "suffered an incalculable loss of prestige, morale, and self-confidence." [Derthick [1990]]

Massive bureaucracy reduces the ruler's incentives to increase his ownership share thereby improving investment incentives. We prove that there exists an equilibrium of the above presented game. The ruler's equilibrium payment to bureaucracy increases when player surplus and the asset value increase. When the game has multiple equilibria, the Pareto-dominant equilibrium has the highest payment to bureaucracy and the lowest ruler's ownership share.

[4] See Wilson [1989] on low incentives in bureaucracies and their tendency to be rigid and reluctant to change, and Dixit [1997] for the game-theoretic analysis.

Empirical evidence [Clarkson [1996]] suggests that contracts between state and local authorities, determining state versus local taxes are incomplete. He argues that contract incompleteness is a result of the inability of both state and city authorities to commit to their *ex ante* tax rate promises. His finding supports the observation from the regulation literature that there is a commitment problem for government authorities and public institutions even in countries with a well-developed legal framework.

The literature on contract law and its enforcement in different economic environments can be classified into three groups. The first group, belonging to industrial organization, investigates the impact of a regulatory regime on investment and analyzes public goods provision.[5] The second relates to international economics; it considers honoring international trade treaties and other government obligations.[6] The third group consists of economic history papers that examine contract enforcement in the absence of a legal system.[7]

The most comprehensive treatment of the subject is provided by the regulation literature. [8] The Coase [1960] theorem asserts that an optimal resource allocation is achievable through market forces, irrespective of the legal liability assignment, if information is perfect and transactions are costless. When the assumption of perfect information does not apply, or when transaction costs are present, government intervention may be desirable. The subject was studied in industrial organization literature and relates to the question of how to provide the efficient amount of specific investment.[9]

Consider the allocation of property rights for an asset produced by a regu-

[5]Public goods provision is closely related to regulation, see Shapiro and Willig [1990] for a series of 'neutrality results', that is, identification of informational environments with no intrinsic difference in the performance of public and regulated private enterprise.

[6]Reviewed by Staiger [1995].

[7]Reviewed by Grief [1996].

[8]Reviewed by Noll [1989].

[9]Laffont and Tirole's [1994] book is an encyclopedic reference on the subject.

lated firm. The firm's ownership rights over the asset are limited and dependent on the regulatory restrictions. The *ex ante* property rights allocation resulting from these restrictions is frequently suboptimal *ex post,* and it is optimal to alter it *ex post* for social efficiency. This causes an *ex post* commitment problem for the regulator and results in investment distortion. The literature bearing on the principal-agent problem is far too extensive for reviewing, or even listing it here. Tirole (1999) provides a comprehensive outlook of the incomplete contracting literature.[10]

Anderlini and Felli [1997] study property rights by using bargaining games. They consider a hold up problem in the presence of *ex ante* contract costs and investigate the conditions under which socially efficient contracts are infeasible. In their initial setup, the distribution of bargaining power across agents is exogenous, and the resulting contracts are constrained inefficient. The inefficiency arises for a certain range of the bargaining powers of the players. Further, Anderlini and Felli [1997] endogenize the distribution of the surplus across players. For a certain range of *ex ante* contract costs, socially desirable contracts are not feasible, irrespective of the surplus distribution. Anderlini and Felli [1997] suggest that when the potential surplus depends on its distribution, the hold up problem is less acute.

Our model is analogous to the Anderlini and Felli [1997] setup when the potential surplus is dependent on its distribution. While in their paper only two-party games are considered, we consider multi-party contracts, and our model permits multi-period contacts. Their model is applicable to a wider range of environments, while our focus is the mechanism behind the surplus distribution.

Greif [1996] points out that historically exchange and contract enforcement existed even in the absence of a legal system. The examination of this phe-

[10]For recent developments see *Review of Economic Studies,* (1999), Vol. 66, Issue 226.

nomenon has not advanced due to the lack of an appropriate framework. However, the existing studies indicate that it is misleading to view contract enforcement based on formal organizations and repeated interactions as substitutes [Greif [1996]]. The intuition for this argument parallels the intuition for why equilibria supported by reputation are typically Pareto inefficient. While in some cases efficiency can be reach through informal means, in both perspectives, historical and theoretical, resource allocations that rely on the rule of law are welfare superior to the ones that rely on informal agreements. The enforcement based on informal interactions relates to formal enforcement as pre-monetary systems of exchange to a monetary system with sophisticated banking institutions.

Our model provides further support for this argument. We show that quasi property rights that rely on the bureaucratic machinery rather than on enforceable contracts are an imperfect substitute for enforceable contracts and real property rights. Davies [1977] provides an example of inefficiency associated with the public provision. He compares the state-owned Trans Australian Airlines (TAA) with the privately-owned Ansett Australian Airlines. Despite the fact that both are tightly regulated by the government, charge the same fares, pay essentially the same wages, and are allowed to compete only with respect to minor amenities, Ansett is more efficient (that is, uses fewer employees to transport a given amount of freight or number of passengers) than TAA. Davies suggests that the difference between the TAA and Ansett relates to the difference in the property rights structure.

The paper is organized as follows: in Section I, the model is presented as an extensive form game. In Section II, the equilibria of the game are characterized and welfare implications analyzed. In Section III, the limitations and extensions of the model are considered, followed by a concluding remark. To ease the exposition technical details and proofs are relegated to the Appendices.

I. The Model

Initially property rights for an asset are unclear. They emerge in the game Γ between a ruler and N identical investors. The game has three stages. In the first stage, the players sign a non-enforceable *ex ante* contract.[11] In the second stage, investors simultaneously make their irreversible investments in the asset, which value is increasing and concave in total investment, or invest in the outside option with a fixed investment return denoted by i. In the third stage, the *ex ante* contract is revised, an *ex post* contract is drawn, and the asset is divided between the players, in accordance with the *ex post* contract. The significance of the *ex ante* contract is its effects on the *ex post* contract.

The ruler possesses some control over the asset, but does not have complete property rights over it. He cannot sell the asset or invest in it, and lacks the right or expertise to use it for production. Thus, to benefit from controlling the asset, the ruler has to contract with the investors. Examples of such assets are numerous: an oil field, a municipal building or agricultural land.[12] To adjust his ownership share the ruler uses bureaucracy. Drastic share adjustments are relatively more costly than minor ones.

Bureaucracy is a government or private institution capable of altering the current division of the surplus between the players. There are many mechanisms to channel the bureaucratic provisions into bargaining powers and through that affect the ownership allocation[13]. We suggest that bureaucratic red tape affects

[11]An absence of enforceability is a stronger constraint on applications than is actually needed. Let investment in the asset be partially contractible, with the effects of contractible and non-contractible investments on its value being independent. Then, one can consider the non-contractible component as a separate asset.

[12]The asset may be interpreted as GNP, investment as aggregate investment, and the ruler as the head of the government. Then, his ownership share is a tax rate, explicit or implicit.

[13]Bureaucratic provisions are laws, decrees, directives, or any other rules relevant for determination of the bargaining balance.

the relative speed of player responses. In many situations, red tape could be circumvented by bribes, which indicates its relevance for surplus redistribution. Red tape is a routine bureaucratic instrument for altering the reaction time, and thus, the distribution of the surplus. Thus, bureaucracy is a device, or a mechanism which affects property right allocation.

In the *ex ante* stage, the ruler chooses his ownership share without incurring any cost. In the *ex post* stage, the ruler can change his ownership share at an exogenous cost. This cost is equal to the expense that bureaucracy incurs to institute the change. Property rights for the asset are allocated according to the outcome of the *ex post* game.

To summarize, the game Γ is the game of complete information. The game has $N+1$ players, the ruler and N investors, and the following order of moves. First, the ruler chooses his *ex ante* share $x \in [0,1]$. Then, the investors choose their investments $q_N \in [0,\infty)$. The total investment $Q = \sum_{n=1}^{N} q_N$ determines the asset value $P(Q)$. Third, the ruler chooses his *ex post* share $y \in [0,1]$.

Each investor's objective is to maximize his profit, $\Pi_N(x, y, \mathbf{q})$, and the ruler's objective is to maximize his net surplus, $V(x, y, \mathbf{q})$. The n-th investor's profit is equal to the value of his *ex post* ownership share less his opportunity cost to funds iq_N, and the ruler's net surplus is equal to the value of his *ex post* ownership share net of his adjustment cost $B(y-x)$:

$$\begin{aligned} \Pi_n(x, y, \mathbf{q}) &= \tfrac{q_n}{Q}(1-y)P(Q) - iq_n, \\ V(x, y, \mathbf{q}) &= yP(Q) - B(y-x), \end{aligned} \tag{1}$$

where $n = 1, ..., N$ and $\mathbf{q} = (q_1, ..., q_N)$ is the vector of investments. The asset value is continuous, concave and three times continuously differentiable at any $Q \in (0,\infty)$. In the absence of property rights conflict investment in the asset is positive, i.e. the derivative of the asset value evaluated at zero exceeds the outside option return $P'(Q)$:

$$P'(Q) > 0,\ P''(Q) < 0,\ \lim_{Q \to 0} P'(Q) \to \infty. \tag{2}$$

The function $B(z)$ is continuous, convex, three times continuously differentiable for any $z \in (0,1)$:

$$B'(z) > 0,\ B''(z) > 0.$$

and can be discontinuous at zero, reflecting the possibility of a fixed-cost.

The equilibrium concept used to analyze this game is a subgame perfect Nash equilibrium that are symmetric with respect to the investors. In such equilibria, investor actions are identical and, since the ruler's objective depends on aggregate investment (not on individual investments), it is sufficient for him to condition his actions on aggregate investment.

II. The Equilibrium of the Game

We say that an investment market is monopolistic if investment in the asset is done by one investor only. If the number of investors is finite, an investment market is imperfectly competitive. A perfect competitive investment market is the limiting case of infinitely many investors.

Definition 1. *An equilibrium is dynamic if the ruler's ex ante and ex post actions differ ($x \neq y$), and static if they are the same ($x = y$).*

Assume the ruler can commit to the *ex ante* contract. Let $\hat{\Gamma}$ denote the game that the committed ruler plays. Its Pareto-dominant outcome will be called the commitment outcome.

Theorem 1. *An equilibrium of the game Γ exists and the ruler's payoff is strictly positive.*

Proof: See Appendix. □

The intuition for the proof is summarized below. The proof is by backward induction. From the ruler's *ex post* first order conditions, he has at most two *ex post* best responses, one in which he adjusts his ownership share, and one in which he does not. Moreover, along the equilibrium path, his *ex post* best response is unique.

Substitution of the ruler's *ex post* best response in investor objective function permits us to solve the investors' maximization problem. There exists one *ex ante* share for which investor best response is not unique, but we prove the uniqueness of an equilibrium that could originate at this share. Therefore, on the equilibrium path, an equilibrium of the subgame that starts at a specific ruler's *ex ante* share is unique.

The last step is to find the ruler's optimal *ex ante* action by using the ruler's *ex post* best response and investor best response. The ruler has at most a finite number of optimal *ex ante* actions, and the game has at most a finite number of equilibria.

Figures I – III provide investor best responses to the ruler's adjustment cost function $B(z)$ with different properties. Figure 1 assumes a non-zero fixed cost ($\lim\limits_{z\to 0} B(z) > 0$), and Figures II and III – a zero ruler's fixed cost ($\lim\limits_{z\to 0} B(z) = 0$) and, respectively, the discontinuous ($\lim\limits_{z\to 0} B'(z) > 0$) and continuous ($\lim\limits_{z\to 0} B'(z) = 0$) first derivative of the function $B(z)$ at zero.

Remark 1. *Without bureaucracy, the ruler's ex post incentive is to expropriate the whole asset, which results in zero surplus for all the players.*

Notice, that the ruler's equilibrium payoff is always strictly positive, because investor best response to any *ex ante* share other than $x = 1$ is strictly positive. When the investment market is imperfectly competitive, investor profit is also always strictly positive. Therefore, from Remark 1 and Theorem 1, the presence of bureaucracy improves player surplus and positively affects society's welfare.[14]

Theorem 2. *There exists a Pareto-dominant equilibrium in the game* Γ*. The asset value in the Pareto-dominant equilibrium is the highest and the rule's ownership share — the lowest within the set of the respective equilibrium values in the game* Γ.

Proof: See Appendix. □

When the game Γ has several equilibria, the ruler's welfare is the same across equilibria, because he moves first and his *ex ante* action determines which equilibrium occurs. In the case of multiplicity of equilibria, investor welfare is the highest in the equilibrium with the highest asset value. This equilibrium is *dynamic* and has the lowest ruler's ownership shares, *ex ante* and *ex post.* The equilibrium with the highest asset value is Pareto-dominant despite the fact that the dissipation of the surplus on bureaucratic costs is the greatest. Thus, an equilibrium with a positive payment to bureaucracy is always Pareto superior to the equilibrium in which the bureaucratic presence is latent. When the equilibrium of the game is *dynamic*, bureaucratic costs are positive, and player commitment payoffs are not achievable. Nevertheless, the players' welfare increases with the bureaucratic machinery.

The usual perception is that bureaucracy guards the ruler's interests. In our model, bureaucracy is really the ruler's tool and safeguard, used to secure a higher payoff for the ruler's than he would have had otherwise. Interestingly, from Remark 1 bureaucratic presence also benefits the investors. With bureaucracy, aggregate equilibrium profit of imperfectly competitive investors is strictly positive, while it is zero otherwise. Bureaucracy imposes a cost on the ruler and through that constrains his ability to expropriate surplus. Bureau-

[14] Society's welfare could be defined as the game surplus. Alternatively, adjustment cost could be included in society's welfare.

cracy improves investor payoffs since the bureaucratic machinery is a constraint on all players.

THEOREM 3. *In an equilibrium of the game* Γ *the asset value and each player payoff are bounded by the respective commitment outcome values. Player surplus reaches the commitment surplus only if the commitment outcome is an equilibrium of the game* Γ.

Proof: See Appendix. □

This result that the equilibrium asset value never exceeds the commitment asset value is intuitive. When commitment outcome is not sustainable, bureaucracy constrains the ruler from expropriating the entire asset, but this constraint is insufficient to eliminate the commitment problem completely. Thus, the equilibrium asset value is between the optimal value and zero, which would have been an equilibrium asset value in the absence of the bureaucracy. To ease the comparative analysis of the games differing by the number of investors, we assume $P''' < 0$.

THEOREM 4. *In the equilibrium of the game* Γ*, the asset value and the ruler's payoff increase in the number of investors.*[15]

Proof: See Appendix. □

It follows from Theorem 1 that the equilibrium is *dynamic* if the asset value exceeds a critical value. By Theorem 4 if the number of investors increases, the asset value also increases. Hence, the equilibrium might switch from a *static* to a *dynamic* one as the number of investors increases. In this case, the bureaucracy starts receiving a positive payment from the ruler, but total player surplus is higher than when the equilibrium is *static.* Figure IV illustrates how the equilibrium of the game Γ depends on the number of investors.

[15]We can prove Theorem 4 without restriction on the third derivative of the function P.

III. Discussion and Conclusion

1. Connection to Contract Theory

Models, which address the hold up problem, investigate the divergence of the *ex ante* and *ex post* incentives to invest. These models propose instruments or mechanisms to lessen or eliminate this divergence. Whether it is possible to find a contractual solution depends on the nature of the divergence and on the proposed mechanism. Hart and Moore [1988] argue that nonverifiability implies noncommitment. In this spirit, our model could be used to study incomplete contracts. Formally, many cases of nonverifiability are indistinguishable from noncommitment.

In this paper, we are studying the problem of underinvestment in environments with unclear property rights. We presented the game Γ as a tool for analyzing this problem. However, the game Γ provides a basic setup for general modeling of environments with limited commitment or costly contracts. Any situation which can be formalized as a resource allocation problem, with *ex ante* allocation that could be altered *ex post* at a cost, convex in the altered parameter, can be modeled with the proposed setup.

Even when contracts are enforceable, renegotiations frequently occur. The model can be adopted to study optimal renegotiation structure, and design optimal penalties for breaking the terms of the contract. The cost of bureaucracy could be interpreted as a penalty imposed on a defaulting party. Specific functional forms reflecting characteristics of a particular environment can be used to design more efficient contractual and legal procedures, with the adjustment cost function viewed as a legal or penalty cost.

2. Extensions and Applications

2A. Strategic Bureaucracy: Our model does not account for strategic bureaucracy, but suggests several modifications for modelling it. The net effect of strategic bureaucracy on the investment allocation is not clear-cut. On one hand, strategic bureaucracy is welfare improving, as it imposes an additional constraint on the ruler and lessens his commitment problem. On the other hand, with strategic bureaucracy, investor ownership share of the asset may be lower due to the ruler's higher *ex ante* share.

2B. Investor Influence on the Ownership Allocation: Our model in its current form does not allow the investors to directly affect the property rights allocation. The investors' only influence on ownership rights is indirect: through their investment choices.

There are several ways to overcome this limitation. One way is to modify the game and allow all players to pay the bureaucracy for a favorable adjustment of their *ex post* ownership shares. Such game is considered in Schwartz (2003) and used to explain a proliferation of the Preferential Trade Areas. An alternative way is to allow the ruler to invest in the asset *ex ante*.

3. Economic Policy and Insecurity of Property Rights

3A. Deregulation and Privatization: An easy reform, especially when the legal system is weak, can be dismantled by the next not necessarily benevolent ruler. We suggest, that a typical complication of economic reforms by bureaucratic resistance to change reflects the role of bureaucracy as a substitute for enforceable contracts.[16] From this angle, bureaucratic resistance to reform appears to be a necessary evil that should be exploited rather than fought. In such an environment it is not plausible to model bureaucracy as passive as it is more likely to play a strategic role.

The investment distortion is more substantial if the investment markets are less competitive. Therefore, monopolistic publicly owned enterprises or regu-

[16] See, for example, a discussion of Russian economic reform in Sachs and Pistor [1997].

lated industries are the most distorted. Paradoxically, monopolistic markets are exactly where regulation is most active.

Hence, deregulation or privatization in industries with less competitive investment markets generates a Pareto improvement that is impossible to mimic even through complete commitment of regulatory authority to a declared regime. This intuition is supported by the current trend of deregulation and denationalization.[17]

3B. Restrictions on Domestic Investment Market: Restricted access to investment markets is frequently observed in environments with insecure property rights. Two types of such restrictions occur. First, the investors might be prohibited from investing abroad or, more generally, capital mobility may be restricted. Second, investor access to certain markets could be restricted. Typically, both types of restrictions are observed simultaneously: when foreign investment is restricted, domestic investors are also subject to the limitations of investment market competitiveness.

The first type of restriction improves the ruler payoff through a lower outside return. The second type of restrictions, i.e., the limitations of investment market competitiveness, is harder to explain. We suggest that such restrictions are likely to occur in repeated settings, when the equilibrium favors investors.

4. Concluding Remark

The beneficial effect of a bureaucratic presence on the investment climate is not at all intuitive. The intellectual resistance to positive outlook on bureaucracies is understandable. Noted for low incentives and inefficiencies, bureaucracies are commonly perceived to be a curse rather than a blessing.

We provide a theoretical argument that explains the persistent correlation of massive bureaucracies and unclear property rights. One could view bureaucratic

[17] See, Joskow and Noll [1994] for an overview of US regulatory reform.

constraints on the ruler's *ex post* share adjustment as a primitive form of division of power between the ruler and the bureaucrats that would gradually be replaced by the rule of law. This paper focuses exactly on this aspect of bureaucratic rule. The model emphasizes that the positive effect of bureaucratic machinery on welfare is due to its ability to restrict the ruler's *ex post* expropriation. From this perspective, bureaucracy is an investor guardian angel.

Appendix I: Figures

Figure I

$$f(x) = \begin{cases} q(x) & : \quad x \in [0, \underline{x}] \\ \bar{q} & : \quad x \in (\underline{x}, \bar{x}] \\ \hat{q}(x) & : \quad x \in [\bar{x}, 1]. \end{cases}$$

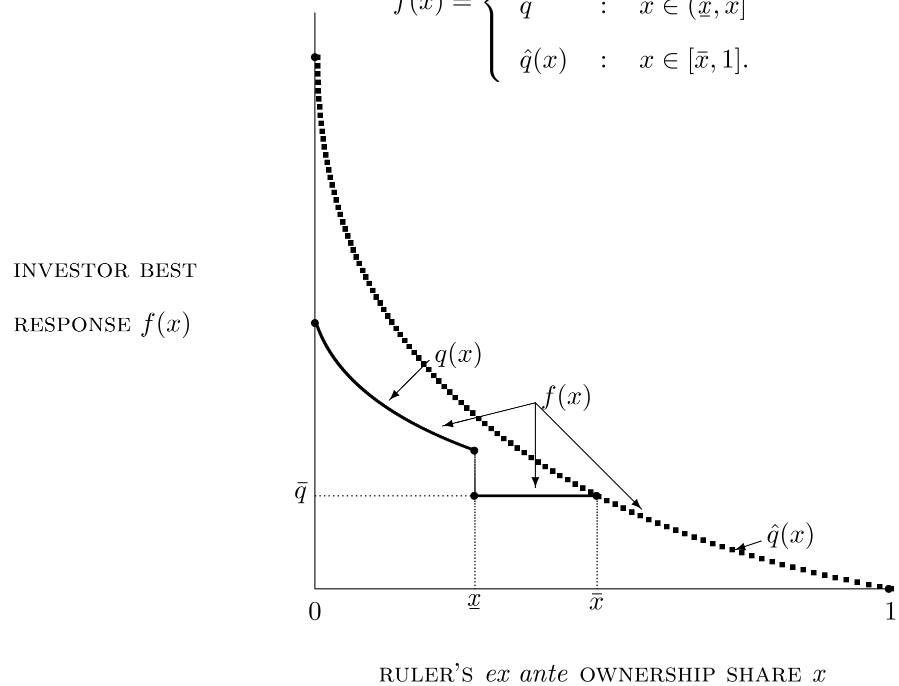

Figure *I* assumes $\lim\limits_{z \to 0} B(z) > 0$ (and $\lim\limits_{z \to 0} B'(z) \geq 0$). Then:

If $x \in [0, \bar{x}]$, *best response investment in the game* Γ *is lower than best response investment in the game* $\hat{\Gamma}$, *and if* $x \in [\bar{x}, 1]$, *best response investments in both games are the same.*

If $x^* \in [0, \underline{x}]$, *the equilibrium of the game* Γ *is dynamic, and If* $x^* \in [\bar{x}, 1]$, *the equilibrium is static. Ex ante shares* $x \in [\underline{x}, \bar{x}]$ *are never the equilibrium ones.*

As the fixed cost decreases, the difference $\bar{x} - \underline{x}$ decreases, and reaches zero $(\bar{x} = \underline{x})$ at $\lim\limits_{z \to 0} B'(z) = 0$, and Figure I turns into Figure II.

Figure II

$$\lim_{z\to 0} B(z) = 0 \ \text{ and } \ \lim_{z\to 0} B'(z) > 0$$

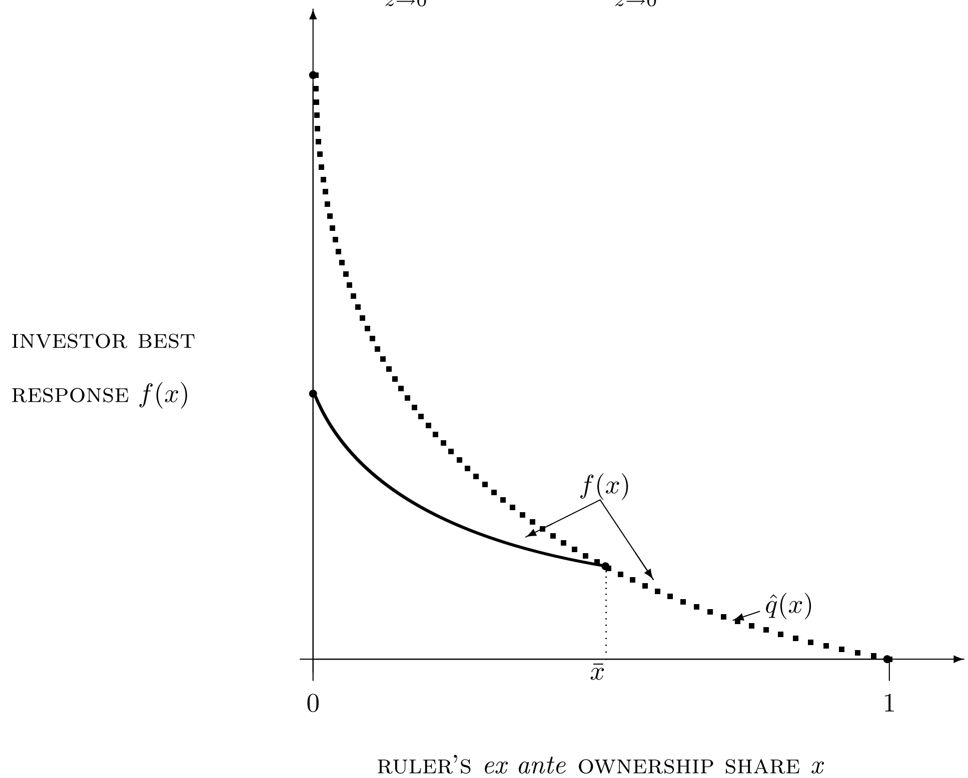

Figure II assumes $\lim_{z\to 0} B(z) = 0$ (and $\lim_{z\to 0} B'(z) > 0$).

As the derivative $\lim_{z\to 0} B'(z) \geq 0$ decreases, the value $\underline{x} = \bar{x}$ increases. When the derivative reaches 0, $\underline{x} = \bar{x}$ reaches 1, and Figure II turns into Figure III.

Figure III

$\lim_{z \to 0} B(z) = 0$ and $\lim_{z \to 0} B'(z) = 0$

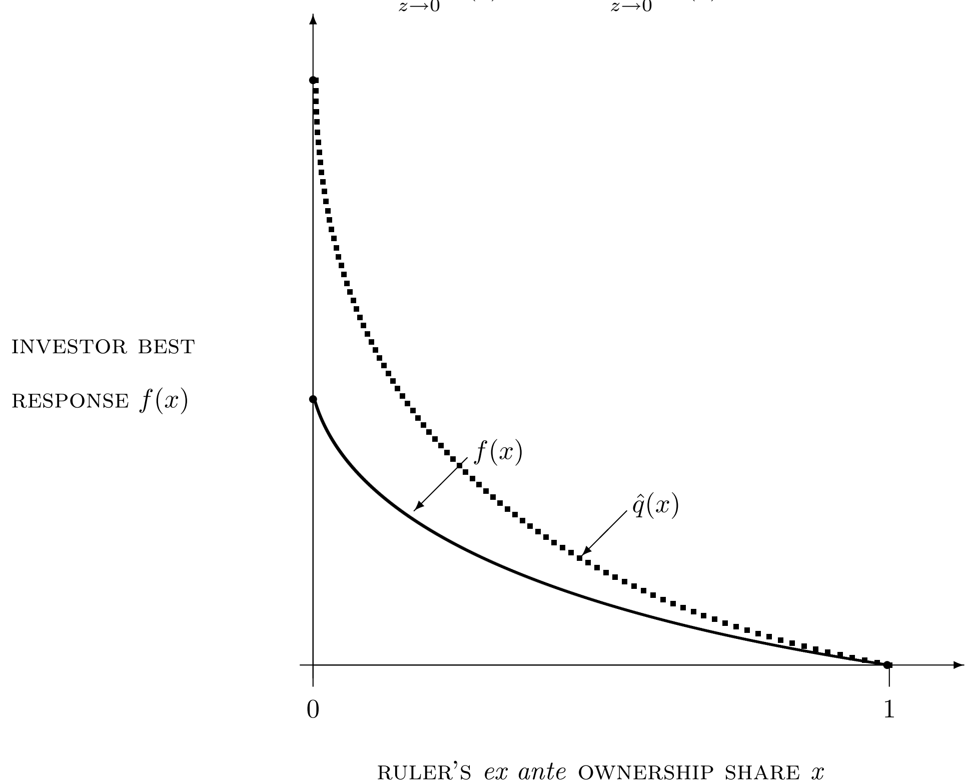

Figure III assumes $\lim_{z \to 0} B(z) = 0$ and $\lim_{z \to 0} B'(z) = 0$. Then, $\underline{x} = \bar{x} = 1$.

In this case, the game Γ *has a unique dynamic equilibrium and the player surplus is below the commitment outcome surplus (Theorem* 3*).*

Figure IV

Equilibria of the Games $\Gamma(N1)$ and $\Gamma(N2)$

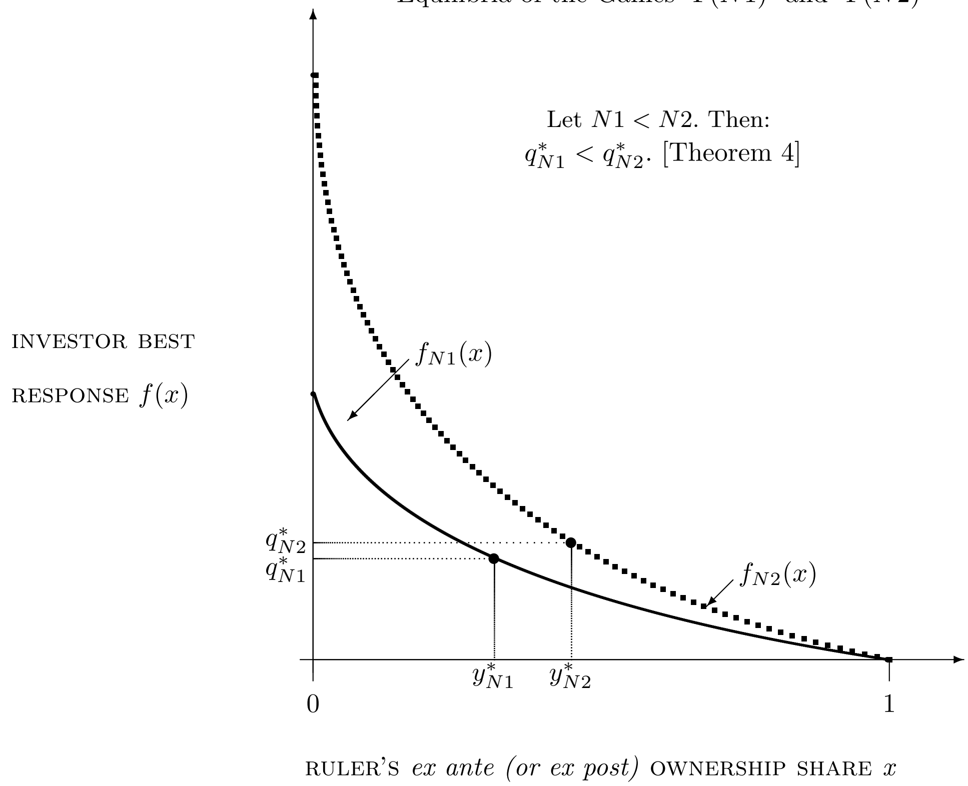

Figure IV assumes $\lim_{z\to 0} B(z) = 0$ and $\lim_{z\to 0} B'(z) = 0$, and $N1 < N2$.

In the equilibrium of the game Γ the asset value and the ruler's payoff are increasing in the number of investors (Theorem 4).

Appendix II: Proofs

Proof of Theorem 1:

The existence of a symmetric equilibrium follows from the construction presented below. In a symmetric equilibrium, investor actions are identical. Since the ruler's objective depends on aggregate investment, it is sufficient for him to condition the actions on aggregate investment. The proof consists of seven Steps and is by backward induction. In Step 1 we solve a system of equations. In Step 2 we solve the game Γ with a restriction for the ruler to employ the same *ex ante* and *ex post* actions. In Step 3 we prove that the solution of the system of equations introduced in Step 1 provides player best responses for a certain interval of the ruler's *ex ante* shares. In Step 4 we show that for a certain interval of the ruler's *ex ante* actions his *ex post* best response action is equal to his *ex ante* action, and investor best response is equal to their best response in the restricted game of Step 2. In Steps 4 - 6 we show that there exist $\underline{x}$ and $\bar{x}$, $0 \leq \underline{x} \leq \bar{x} \leq 1$, such that the equilibrium in the subgame that starts after $x \in [0, \underline{x}]$ is *dynamic,* it is *static* for all $x \in [\bar{x}, 1]$, and $x \in (\underline{x}, \bar{x})$ are never the equilibrium actions in the game Γ. In Step 7 we establish the uniqueness of the equilibrium in the subgame that starts after $x \in [0, \underline{x}] \cup [\bar{x}, 1]$, prove the existence of an equilibrium and show that the ruler's equilibrium payoff is strictly positive.

Step 1: To simplify, we extend functions defined on open intervals to the closed intervals by continuity. Consider the following system of equations:

$$P(Q) - B'(y - x) = 0, \tag{3}$$

$$(1 - y)A(Q) - i = 0, \tag{4}$$

$$y > x, \tag{5}$$

where $Q \in [0, \infty)$, $x, y \in [0, 1]$, and $A(Q)$ is equal to

$$A(Q) = \frac{1}{N} P'(Q) + (1 - \frac{1}{N}) \frac{P(Q)}{Q}. \tag{6}$$

From properties of the function P, the function A is continuous and twice continuously differentiable for all $Q \in [0, \infty)$ (the function A is a weighted average of marginal and average costs).

Claim 1. *The system of equations (3) - (5) has at most one solution. This solution $(y(x), Q(x))$ is continuous, twice continuously differentiable, and $Q'(x) < 0$. One can find such an $x_b \in [0, 1]$ that for all $x \in [0, x_b)$ a solution of the system of equations (3) - (5) exists, and for all $x \in [x_b, 1]$ there is no solution.*

Proof of Claim 1: Let b denote $\lim_{v \to 0} B'(v)$ and Q_b – the solution of equation $P(Q) = b$. For $Q < Q_b$ the subsystem of equations (3) and (5) has no solution, because from properties of the functions B and P for any $y > x$:

$$P(Q) \leq P(Q_b) = b < B'(y - x). \tag{7}$$

Keep Q and x fixed and differentiate equation (3) with respect to y to show that the derivative is negative:

$$-B''(y - x) < 0. \tag{8}$$

From equation (8) and properties of the functions P and B, there exists a unique solution of equation (3) for any fixed x and $Q \in (Q_b, \infty)$. Let $y^Q(x)$ denote this solution. Differentiate equation (3) with respect to Q and keep x fixed to show that the derivative $\frac{dy^Q(x)}{dQ}$ is positive:

$$\frac{dy^Q(x)}{dQ} = \frac{P'(Q)}{B''(y^Q(x) - x)} > 0. \tag{9}$$

Use equations (7) and (9) and properties of the functions A, P and B to show that the derivative of equation (4) with respect to Q is negative:

$$(1 - y)A'(Q) - \frac{P'(Q)}{B''(y^Q(x) - x)} A(Q) < 0,$$

because the function A' is negative

$$A'(Q) = \frac{1}{N} P''(Q) + (1 - \frac{1}{N}) \frac{1}{Q} \left[P'(Q) - \frac{P(Q)}{Q} \right] < 0. \tag{10}$$

Thus, there exists a unique interior solution $Q(x)$ of equation (4). (A boundary point $Q = 0$ is optimal only when $x = 1$, in which case the system of equations (3) - (5) has no solution. A boundary point $Q \to \infty$ is never optimal). From uniqueness and existence of $y^Q(x)$ and $Q(x)$ there exists a unique $y(x) = y^{Q(x)}(x)$ and a unique solution $(y(x), Q(x))$ of the system of equations (3) - (5) for all x such that $Q(x) \in (Q_b, \infty)$. From the continuity and differentiability of the underlying functions this solution $(y(x), Q(x))$ is continuous and twice continuously differentiable. Differentiate equations (3) and (4) with respect to x and apply the implicit function theorem to show that the derivative $Q'(x)$ is negative

$$Q'(x) = \frac{i}{(1 - y)^2 A'(Q) - \frac{iP'(Q)}{B''(y - x)}} < 0, \tag{11}$$

due to properties of the functions A, P and B.

Let x_b denote the solution of equation $Q(x) = Q_b$. The system of equations

(3) - (5) has no solution for all $x \in [x_b, 1]$, because from equation (11) $Q(x) < Q_b$ for all $x \in [x_b, 1]$, and for all $x \in [0, x_b)$ there exists a unique solution $(y(x), Q(x))$. $\square$

STEP 2: Let the game $\hat{\Gamma}$ denote the game Γ in which the ruler's *ex post* action is restricted to be his *ex ante* action.

Lemma 2.1. For any $x \in [0, 1)$ there exists a unique solution $\hat{Q}(x)$ of equation

$$(1 - x)A(Q) - i = 0, \tag{12}$$

where A is given by equation (6) and $Q \in [0, \infty)$. The function $\hat{Q}$ is continuous, twice continuously differentiable and $\hat{Q}' < 0$.

Proof of Lemma 2.1: From equations (2) and (6)

$$\lim_{Q \to 0} A(Q) \to \infty \quad \text{and} \quad \lim_{Q \to \infty} A(Q) > 1.$$

Thus, from the intermediate value theorem, there exists an interior solution of equation (12) for $x \in [0, 1)$. From equation (12), its derivative with respect to Q is negative:

$$(1 - x)A'(Q) < 0 : x \in [0, 1),$$

because A' is negative from equation (10). Thus, the solution $\hat{Q}(x)$ of equation (12) exists and is unique. From properties of the underlying functions, the function $\hat{Q}(x)$ is continuous and twice continuously differentiable. Differentiate equation (12) with respect to x and use the implicit function theorem to show that the derivative $\hat{Q}'(x)$ is negative:

$$\hat{Q}'(x) = \frac{i}{(1 - x)^2 A'(\hat{Q}(x))} < 0, \tag{13}$$

because A' is negative from equation (10). $\square$

Lemma 2.2. There exists a unique symmetric equilibrium $\hat{\mathbf{q}}(x)$ *in subgame of the game* $\hat{\Gamma}$ *that starts after* x*, where* $\hat{\mathbf{q}}(x) = (\hat{q}(x), \ldots, \hat{q}(x))$*,* $\hat{q}(x) = \frac{\hat{Q}(x)}{N}$*, and* $\hat{Q}(x)$ *is a solution of equation (12). The function* $\hat{q}$ *is continuous, twice continuously differentiable and* $\hat{q}'(x) < 0$ for all $x \in [0, 1]$.

Proof of Lemma 2.2: First, we show that investment $q(x)$ is optimal for each investor given that all other investor actions are equal to $q(x)$. Second, we prove that no other vector of investments can be a symmetric investor best response.

1. Let $\hat{\mathbf{q}}(x) = (\frac{\hat{Q}(x)}{N}, \ldots, \frac{\hat{Q}(x)}{N})$ be the vector of investments. Then, from Lemma 2.1 each investor's first order conditions are fulfilled:

$$\frac{\Pi_n(x, x, \hat{\mathbf{q}}(x))}{dq_n} = (1 - x)A(Q) - i = 0,$$

where $n = 1, \ldots, N$. Thus, $\hat{\mathbf{q}}(x)$ is a critical point of the function Π_n, because Π_n is concave in q_n:

$$\frac{d^2\Pi_n(x, x, \hat{\mathbf{q}}(x))}{dq_n^2} = (1 - x)A'(Q) < 0,$$

which provides that each investor profit is maximized at $\hat{\mathbf{q}}(x)$.

2. The proof is by contradiction. Let $\tilde{\mathbf{q}}(x) = (\frac{\tilde{Q}(x)}{N}, \ldots, \frac{\tilde{Q}(x)}{N})$, with $\tilde{Q}(x) \neq \hat{Q}(x)$, be another symmetric investor best response. Then, each investor's first order conditions are:

$$\frac{\Pi_n(x, x, \tilde{\mathbf{q}}(x))}{dq_n} = (1 - x)A(\tilde{Q}) - i = 0,$$

which contradicts the uniqueness of the solution of equation (12). Thus, the symmetric best response $\hat{q}(x)$ is unique. From Lemma 2.1 and equation (13) the function $\hat{q}$ is continuous, twice continuously differentiable and decreasing in

x:

$$\hat{q}'(x) < 0, \tag{14}$$

for all $x \in [0,1]$. □

Claim 2. *There exists an equilibrium of the game* $\hat{\Gamma}$.

Proof of Claim 2: From equation (1) and Lemma 2.2, the ruler's objective $\hat{V}(x, \mathbf{q})$ in the game $\hat{\Gamma}$ is to maximize:

$$\hat{V}(x, \mathbf{q}) = V(x, x, \mathbf{q}) = xP(\hat{Q}(x)),$$

where $\hat{Q}(x) = N\hat{q}(x)$ is aggregate best response investment. The ruler's payoff is continuous for all $x \in [0,1]$, is zero at $x = 0$ and $x = 1$, and bounded by $[0, P^{\max}]$, where $P^{\max} = P(\hat{Q}(0))$. Thus, the ruler's payoff is continuous and bounded on the compact interval $[0,1]$. Then, a set $\hat{X}$ of maximizers of the function $\hat{V}(x, \mathbf{q})$ is non-empty. From Lemma 2.2 there exists a unique investor best response for any x, and, thus for all $\hat{x} \in \hat{X}$. Therefore, there exists an equilibrium of the game $\hat{\Gamma}$, with player actions $(\hat{x}, \hat{q}(\hat{x}))$ and $\hat{x} \in \hat{X}$. □

Step 3:

Claim 3. *The equilibrium of the subgame that starts after* $x \in [0, x_b)$*, in which the ruler's ex post best response is greater than* x *is unique. Player actions in this equilibrium are* $(y(x), \mathbf{q}(x))$*, with* $\mathbf{q}(x) = (q(x), \dots, q(x))$*,* $q(x) = \frac{Q(x)}{N}$ *and* $(y(x), Q(x))$ *is a solution of the system of equations (3) - (5).*

Proof of Claim 3: The ruler's *ex post* first order conditions coincide with equation (3). Its solution $y^Q(x)$ provides the ruler's best response y to any fixed x and Q, if $y > x$. From Claim 1 if $y > x$, there exists a unique ruler's *ex post* action $y^Q(x) > x$ for any fixed $x \in [0,1]$ and $Q \in (Q_b, \infty)$:

$$V(x, y^Q(x), \mathbf{q}) = \max_{y>x} V(x, y, \mathbf{q}),$$

where $Q = \sum_{n=i}^{N} q_n$. From Claim 1 that there exists a unique solution $(y(x), Q(x))$ of the system of equations (3) - (5) for all $x \in [0, x_b)$. From the argument analogous to Lemma 2.2, if the *ex post* best response $y > x$ and investor actions are symmetric maximum profit is achieved at a unique $\mathbf{q}(x) = (q(x), \ldots, q(x))$, with $q(x) = \frac{Q(x)}{N}$. The function q is continuous, twice continuously differentiable and

$$q'(x) < 0. \tag{15}$$

Thus, if the ruler's *ex post* best response y is greater than x, a solution $(y(x), Q(x))$ of the system of equations (3) - (5) provides unique equilibrium aggregate investment $Q(x)$ and the ruler's *ex post* action $y(x)$. □

STEP 4: Let $G(x)$ be defined as

$$G(x) = (y(x) - x)P(Q(x)) - B(y(x) - x),$$

and notice that $G(x)$ equals to the ruler's maximum gain from the *ex post* share adjustment. Let player actions and payoffs indexed by the superscript '*d*' refer to the case of a *dynamic* ruler's *ex post* best response, i.e. $y > x$, and by the superscript '*s*' to a *static* one, i.e. $y = x$. When $G(x) > 0$, the ruler's *ex post* best response is *dynamic*, because his gain from the share adjustment is positive.

CLAIM 4. *If $G(x) < 0$, the ruler's ex post best response is static for all $x \in [0, 1)$. If*

$$G(x) = 0 \tag{16}$$

for some $\bar{x} \in [0,1)$*, this* $\bar{x}$ *is unique and* $\bar{x} \in [0, x_b)$*. The highest share for which the ruler's ex post best response is nonunique is* $\bar{x}$*, and all* $x \in (\bar{x}, 1)$ *his ex post best response is static.*

Proof of Claim 4: From the definition, the function G is continuous, twice continuously differentiable, and decreasing in x:

$$G'(x) = (y(x) - x) P'(Q) Q'(x) < 0.$$

Since the function G is decreasing in x, if $G(0) < 0$, equation $G(x) < 0$ holds for all $x \in [0,1)$, and the ruler's *ex post* best response is *static*. If

$$\lim_{v \to 0} B(v) = 0 \quad \text{and} \quad \lim_{v \to 0} B'(v) = 0,$$

there exists no solution of equation (16), because $G(x) > 0$ for all $x \in [0,1)$. Since the function G is decreasing in x, if $G(0) > 0$, from properties of the functions P and B there exists a unique solution of equation (16) if

$$\lim_{v \to 0} B(v) \neq 0 \quad \text{or} \quad \lim_{v \to 0} B'(v) \neq 0.$$

Let $\bar{x}$ denote this solution. When $b > 0$, there exists $\varepsilon > 0$ and $\tilde{x} = x_b - \varepsilon$ such that $(y(\tilde{x}) - \tilde{x})P(Q(\tilde{x}))$ is smaller than b. Then, $G(\tilde{x}) < 0$ and the ruler's *ex post* best response is *static* for all $x \in [\tilde{x}, 1]$. Therefore,

$$\bar{x} < \tilde{x} = x_b - \varepsilon < x_b.$$

Clearly, for all $x \in (\bar{x}, 1]$ the ruler's *ex post* best response is *static*, because $G(x) < 0$. When $G(\bar{x}) = 0$ the ruler's *dynamic* payoff $V^d(\bar{x}) = V(\bar{x}, y(\bar{x}), \mathbf{q}(\bar{x}))$ and his *static* payoff $V^s(\bar{x}) = V(\bar{x}, \bar{x}, \mathbf{q}(\bar{x}))$ are equal. □

Step 5: Let $\bar{q}$ denote $\hat{q}(\bar{x})$.

Claim 5. *There exists at most one $\underline{x}$, to which investor best response is nonunique. When $\underline{x}$ exists, we have $\underline{x} \leq \bar{x}$ and:*

(1) for $x \in [0, \underline{x}) \cup (\bar{x}, 1]$ there exists a unique equilibrium in the subgame of the game Γ that starts after x,

(2) for $x \in [0, \underline{x})$ player best responses are dynamic, and for $x \in (\bar{x}, 1]$ – static,

(3) for $x \in (\underline{x}, \bar{x})$ investor best responses are $\bar{q}$.

Proof of Claim 5: From equations (4), (12), and (14) for all $x \in [0, x_b)$

$$q(x) = \hat{q}(y(x)) < \hat{q}(x). \tag{17}$$

From Claim 4, for $x \in (\bar{x}, 1]$ the ruler's *ex post* best response is *static*, and $\underline{x} \leq \bar{x} < x_b$. From Claim 2, investor best response $\hat{\mathbf{q}}(x)$ is unique for all $\underline{x} \leq \bar{x}$.

For $x \in [0, \bar{x})$ investment $q > \bar{q}$ cannot be sustained statically, because $G(x) > 0$. From Claim 4, for $x < \bar{x}$ the ruler's *ex post* best response to $q > \bar{q}$ is *dynamic*. If $x \in [0, \bar{x})$ and investment $q^s < \bar{q}$ is sustainable, $\bar{q}$ is also sustainable and preferred by the investors to q^s. Thus, if $x \in [0, \bar{x})$ and $y = x$ is optimal for the ruler, $\bar{q}$ is optimal for the investors.

Further proof of Claim 5 is by contradiction. Let investor best response to x_1 and x_2, $x_1 < x_2$, be nonunique:

$$\begin{aligned} \Pi(x_1, y(x_1), \mathbf{q}_1^d) &= \Pi(x_1, x_1, \mathbf{q}_1^s) \\ \Pi(x_2, y(x_2), \mathbf{q}_2^d) &= \Pi(x_2, x_2, \mathbf{q}_2^s). \end{aligned} \tag{18}$$

Here $\mathbf{q}^d_{\mu \in \{1,2\}} = (q(x_\mu), \ldots, q(x_\mu))$, and $\mathbf{q}^s_{\mu \in \{1,2\}} = (\bar{q}, \ldots, \bar{q})$, because $x_\mu \in [0, \bar{x})$. From equations (14), (15) and (17) we have

$$\bar{q} < q(x_2) < q(x_1). \tag{19}$$

Use equations (18) and (19) to show that the difference between *static* and *dynamic* profit when the ruler's *ex ante* action is equal to x_1 is positive:

$$\begin{aligned} &\Pi(x_1, y(x_1), \mathbf{q}_1^d) - \Pi(x_1, x_1, \bar{\mathbf{q}}) > \\ &\Pi(x_1, y^{Q_2}(x_1), \mathbf{q}_2^d) - \Pi(x_1, x_1, \bar{\mathbf{q}}) = \\ &(x_2 - x_1)[P(Nq_2(x)) - P(N\bar{q})] > 0. \end{aligned} \tag{20}$$

Here $Q_2 = Nq(x_2)$ and $y^{Q_2}(x_1)$ is a solution of the system of equations (3) and (5) for $x = x_1$ and $Q = Q_2$. Equation (20) contradicts the assumption of non-unique investor best response at x_1. Therefore, the action $\underline{x}$ is either unique or does not exist.

Let $x_2 = \underline{x}$. From equation (20) for all $x \in [0, \underline{x})$ investor best response is unique and *dynamic.* Obviously, $\bar{q}$ is sustainable at any $x \in (\underline{x}, \bar{x})$ if $\bar{q}$ is sustainable at $\underline{x}$.The analog of equation (20) for x_2 and x_3, where $x_2 < x_3$, and $x_3 < \bar{x}$ provides that investor *static* profit at x_3 is higher than their *dynamic* profit at x_3*:*

$$\Pi(x_3, x_3, \bar{\mathbf{q}}) - \Pi(x_3, y(x_3), \mathbf{q}_3^d) > (x_3 - x_2)[P(Nq(x_3)) - P(N\bar{q})] > 0.$$

Thus, for all $x \in (\underline{x}, \bar{x})$ each investor best response is *static* and equal to $\bar{q}$. □

Step 6: Let $f(x)$ and $u(x)$ denote:

$$f(x) = \begin{cases} q(x) : x \in [0, \underline{x}] \\ \hat{q}(x) : x \in [\bar{x}, 1] \end{cases} \quad \text{and} \quad u(x) = \begin{cases} y(x) : x \in [0, \underline{x}] \\ x : x \in [\bar{x}, 1]. \end{cases} \tag{21}$$

We define the functions f and u on the intervals $[0, \underline{x}]$ and $[0, \underline{x}]$ only. From the continuity and differentiability of the underlying functions, the functions f and u are continuous and twice continuously differentiable for all $x \in [0, \underline{x}] \cup [\bar{x}, 1]$, and from equations (14), (15) and (21) the function f is decreasing in x:

$$f'(x) < 0 \qquad \forall x \in [0, \underline{x}] \cup [\bar{x}, 1].$$

Claim 6. *For all $x \in [0, \underline{x}] \cup [\bar{x}, 1]$ there exists a unique equilibrium in the subgame of the game Γ that starts after x. The ruler's and the investors' equilibrium actions in this subgame are given by the functions u and f.*

Proof of Claim 6: First, let $x \in [\bar{x}, 1]$. From Claim 5 the ruler's *ex post* best response is *unique* and *static* for all $x \in (\bar{x}, 1]$. When $x = \bar{x}$ only the ruler's *static ex post* best response ($y = x$) is his equilibrium action, as the investors strictly prefer this action. By investing $\bar{q} - \epsilon$, where $\epsilon > 0$, they could secure for themselves a profit arbitrarily close to their profit at their preferred outcome (i.e. *static)*. Thus, player best responses along the equilibrium path are *static* for all $x \in [\bar{x}, 1]$, and their maximization problems coincide with their optimization in the game $\hat{\Gamma}$, where $y = x$ and each investor best response is equal to $\hat{\mathbf{q}}(x)$. In the interval $[\bar{x}, 1]$ the functions u and f coincide with player *static* best responses $\hat{q}(x)$ and x. Thus, Claim 6 is proven for the interval $[\bar{x}, 1]$.

Next, let $x \in [0, \underline{x}]$. From Claims 3 and 5, for all $x \in [0, \underline{x})$ player best responses are unique and *dynamic*. When $x = \underline{x}$ only *dynamic* investor best response is their equilibrium action, because it is strictly preferred by the ruler. He can secure for himself a payoff arbitrarily close to his payoff in his preferred *dynamic* outcome by choosing his *ex ante* action $\underline{x} - \epsilon$, where $\epsilon > 0$. Thus, for all $x \in [0, \underline{x}]$ player best responses are unique and *dynamic*. In the interval $[0, \bar{x}]$ the functions f and u coincide with player *dynamic* best responses $q(x)$ and $y(x)$, and Claim 6 is proven. □

Step 7: Let V_f denote:

$$V_f(x) = u(x)P(Nf(x)) - B(u(x) - x) : \forall x \in [0, \underline{x}] \cup [\bar{x}, 1], \tag{22}$$

where the functions f and u are given by equation (21). The function V_f is continuous and two times continuously differentiable.

Claim 7. *In the game Γ, any ruler's equilibrium ex ante action belong to the intervals $[0, \underline{x}]$ and $[\bar{x}, 1]$.*

Proof of Claim 7: The actions from the interval $(\underline{x}, \bar{x})$ cannot be the ruler's *ex ante* equilibrium actions, because to any $x \in (\underline{x}, \bar{x})$ the ruler strictly prefers $\bar{x}$. □

We have shown in Claim 6 that for all $x \in [0, \underline{x}] \cup [\bar{x}, 1]$, maximization of $V(x, y, \mathbf{q})$ and $V_f(x)$ results in the same set of the ruler's *ex ante* actions, and in Claim 7 that $x \in (\underline{x}, \bar{x})$ are never the equilibrium actions.

From Claim 6 the ruler's equilibrium payoff in any subgame of the game Γ that starts after $x \in [0, \underline{x}] \cup [\bar{x}, 1]$ is given by the function V_f. The ruler's payoff V_f is continuous on the compact intervals $[0, \underline{x}] \cup [\bar{x}, 1]$ and bounded from below and above by $[0, P^{\max}]$, where $P^{\max} = P(\hat{Q}(0))$. Thus, there exists at least one maximizer of the function V_f on each interval, and at least one global maximizer of the ruler's payoff. Let X^* denote the set of maximizers of the function V_f. From Claim 6, there exists a unique equilibrium in each subgame that originates at any $x \in [0, \underline{x}] \cup [\bar{x}, 1]$, and, thus, a unique equilibrium in each subgame that starts after any $x^* \in X^*$. Since we have proven that the set X^* is non-empty, there exists an equilibrium of the game Γ. The ruler's equilibrium payoff is strictly positive, because his payoff is strictly positive for any $x \in (0, 1)$, and Theorem 1 is proven. □

Proof of Theorem 2:

STEP 1: When the game Γ has multiple equilibria, the ruler's payoff is the same in all of them, since the ruler moves first and his *ex ante* equilibrium action determines which equilibrium occurs. Let X^{s*} and X^{d*} denote the sets of the ruler's *ex ante* actions such that for any $x^{s*} \in X^{s*}$ we have $y^{s*} = x^{s*}$, and for any $x^{d*} \in X^{d*}$ we have $y^{d*} > x^{d*}$. Let $\underline{x}^{s*}$ and $\underline{x}^{d*}$ denote the respective infimums:

$$\underline{x}^{s*} = inf\{X^{s*}\} \quad \text{and} \quad \underline{x}^{d*} = inf\{X^{d*}\},$$

and

$$\underline{x}^{s*} \in X^{s*} \quad \text{and} \quad \underline{x}^{\ d*} \in X^{d*},$$

because the set X^* is compact. From Theorem 1:

$$\underline{x}^{d*} < \underline{x}^{s*},$$

because

$$\underline{x}^{d*} \in [0, \underline{x}], \quad \underline{x}^{s*} \in [\bar{x}, 1] \quad \text{and} \quad \bar{x} < \underline{x}.$$

Let Π_f denote:

$$\Pi_f(x) = (1 - u(x))P(Nf(x))\frac{f(x)}{Nf(x)} - if(x),$$

where $x \in [0, \underline{x}] \cup [\bar{x}, 1]$. Investor equilibrium payoff in the subgame that starts after $x \in [0, \underline{x}] \cup [\bar{x}, 1]$ is given by the function Π_f. The proof of this fact is the same as our proof in Theorem 1 of an analogous fact about the ruler's payoff V_f. Next, we show that for each interval, $[0, \underline{x}]$ and $[\bar{x}, 1]$, profit is maximal in the equilibrium in which the ruler's share is the lowest within the set of his equilibrium shares:

$$\underline{x}^{d*} = \arg\max_{x^* \in X^{d*}} \Pi_f(x^*) \quad \text{and} \quad \underline{x}^{s*} = \arg\max_{x^* \in X^{s*}} \Pi_f(x^*).$$

Investor profit is decreasing in the ruler's *ex ante* action:

$$\frac{d\Pi_f(x)}{dx} < 0 : x \in [0, \underline{x}] \cup [\bar{x}, 1].$$

Thus, on each interval $[0, \underline{x}]$ and $[\bar{x}, 1]$, maximum investor profit is reached at $\underline{x}^{d*}$ and $\underline{x}^{s*}$, respectively, and from Theorem 1:

$$x^{d*} < u(x^{d*}) \leq \underline{x} \leq \bar{x} \leq x^{s*}. \tag{23}$$

The last step is to compare investor profits in the equilibria in which the ruler's *ex ante* actions are $\underline{x}^{d*}$ and $\underline{x}^{s*}$, because we have proven that only these two equilibria can be Pareto-dominant. When the equilibrium is not unique the asset value is higher in any *dynamic* equilibrium than in any *static* one: otherwise, the ruler will not adjust his ownership share:

$$P(Nq^{d*}) > P(Nq^{s*}), \quad q^{d*} > q^{s*} = \bar{q}. \tag{24}$$

From Claim 2 of Theorem 1 at any x for all $q < \hat{q}(x)$, investor profit increases as investment increases. From equations (17), (23) and (24):

$$q^{d*} = q(x^{d*}) = \hat{q}(u^{d*}) < \bar{q},$$

which provides a higher investor profit in a *dynamic* equilibrium:

$$\Pi^{d*} = \Pi(x^{d*}, u^{d*}, \mathbf{q}^{d*}) \geq \Pi(u^{d*}, u^{d*}, \bar{\mathbf{q}}) > \Pi(\bar{x}, \bar{x}, \bar{\mathbf{q}}) = \Pi(x^{s*}, u^{s*}, \mathbf{q}^{s*}) = \Pi^{s*},$$

where $u^{d*} = u(x^{d*})$. Since the ruler's *ex ante* action determines which equilibrium occurs, his payoff is the same in all equilibria. Investor profit is the highest in the equilibrium with the lowest ruler's ownership and highest asset value. Therefore, this equilibrium is the Pareto-dominant. □

Proof of Theorem 3:

Step 1

Claim 1. *The ruler's commitment payoff is an upper bound for his payoffs in the game* Γ.

Proof of Claim 1: The proof is by contradiction. Let there exists an equilibrium of the game Γ, with the ruler's payoff V^*, $V^* > \hat{V}$, where $\hat{V}$ is the ruler's payoff in the Pareto-Dominant equilibrium of the game $\hat{\Gamma}$:

$$V^* = u^* P(Nq^*) - B(u^* - x^*) > \hat{x} P(N\hat{q}) = \hat{V},$$

where $(x^*, u^*, \mathbf{q}^*)$ and $(\hat{x}, \hat{\mathbf{q}})$ denote the respective equilibrium actions in the games Γ and $\hat{\Gamma}$, and

$$\mathbf{q}^* = (q^*, \dots, q^*), \; \hat{\mathbf{q}} = (\hat{q}, \dots, \hat{q}).$$

The contradiction is immediate if the equilibrium of the game Γ is *static*, i.e. if $u^* = x^*$. Thus, we have to consider only $x^* \in [0, \underline{x}]$, and, from Theorem 1:

$$u^* = u(x^*) > x^*, \; q^* = q(x^*).$$

From equation (17), when the equilibrium is *dynamic*:

$$q^* = \hat{q}(u^*) < \hat{q}(x^*).$$

Compute the ruler's payoff in the game $\hat{\Gamma}$ at the action u^*:

$$\hat{V}(u^*, \hat{\mathbf{q}}(u^*)) = u^* P(N\hat{q}(u^*)) > u^* P(Nq^*) > V^* > \hat{V} = \hat{x} P\left(N\hat{q}\right),$$

and, thus, the ruler's payoff from u^* in the game $\hat{\Gamma}$ is higher than V^*, which contradicts to the assumption that $\hat{V} < V^*$ is an equilibrium. □

Step 2

Claim 2. *Claim 2. The equilibrium asset value in the game* Γ *is bounded by the commitment asset value.*

Proof of Claim 2: The statement of Claim 2 is trivial when the equilibrium of the game Γ is *static*. Thus, our considerations are limited by *dynamic* equilibria, i.e. by the case when the ruler's *ex ante* action $x \in [0, \underline{x}]$.

The proof of Claim 2 is by contradiction. Let there exist an equilibrium of the game Γ with $q^* > \hat{q}$, where $q^* = q(x^*)$ and $\hat{q} = \hat{q}(\hat{x})$ are the asset values in the games Γ and $\hat{\Gamma}$ with the equilibrium actions (x^*, u^*, q^*) and $(\hat{x}, \hat{q})$. Then,

$$\hat{V}(u^*, \hat{\mathbf{q}}(u^*)) \leq \hat{V}(\hat{x}, \hat{\mathbf{q}}(\hat{x})),$$

because $\hat{V}(\hat{x}, \hat{\mathbf{q}}(\hat{x}))$ is an equilibrium. Consider the ruler's *ex ante* action $\tilde{x}$ such that $u(\tilde{x}) = \hat{x}$. Then, the ruler's payoff $V_f(\tilde{x})$ is higher than his equilibrium payoff $V_f(x^*)$:

$$\begin{aligned} V_f(\tilde{x}) &= u(\tilde{x})P(Nq(\tilde{x})) - B(u(\tilde{x}) - \tilde{x}) \\ &= \hat{x}P(Nq(\tilde{x})) - B(\hat{x} - \tilde{x}) = \hat{V}, \\ V_f(x^*) &= u(x^*)P(Nq(x^*)) - B(u^* - x^*) \\ &= \hat{V}(u^*, \hat{\mathbf{q}}(u^*)) - B(u^* - x^*). \end{aligned}$$

From equations (3) and (15) and properties of the function B:

$$B(u^* - x^*) > B(\hat{x} - \tilde{x}),$$

which provides:

$$V_f(\tilde{x}) > V_f(x^*),$$

a contradiction to the assumption that (x^*, u^*, q^*) are the equilibrium actions of the game Γ. Therefore, $q^* \leq \hat{q}$. From equation (17) we have $q(x) > \hat{q}(\hat{x})$ for all $x \in [0, \tilde{x})$. We have proven that such asset value cannot occur in the equilibrium of the game Γ. Thus, $x^* \notin [0, \tilde{x})$. Differentiate equation (3) and use of equation (13) to prove that

$$\frac{dy\,(x)}{dx} \in [0, 1]\,,$$

and since $x^* > \tilde{x}$, we have:

$$u^* = u(x^*) > u(\tilde{x}) = \hat{x}.$$

Thus, investor equilibrium profit in the game Γ is bounded by their equilibrium profit in the game $\hat{\Gamma}$: because investor profit is decreasing in their ownership share. □

Note that we have proven a stronger version of Theorem 3 than we stated in the main text of this paper. We have shown that the equilibrium asset value in the game Γ is bounded by the lowest asset value within the set of equilibrium asset values in the game $\hat{\Gamma}$. We will use this fact in our proof of Theorem 4.

PROOF OF THEOREM 4

STEP 1: Let $N1 < N2$ and compare the games $\Gamma(N1)$ and $\Gamma(N2)$, where $\Gamma(N)$ denotes the game Γ with N investors, and the subscript N is used to denote the respective game.

CLAIM 1. *In the game $\Gamma(N)$ the ruler's equilibrium payoff increases in N.*

Proof of Claim 1: When ruler's *ex ante* actions in both games are the same, from equations (4) and (12) aggregate best response investment is higher in the game $\Gamma(N2)$:

$$f_{N1}(x) \times N1 < f_{N2}(x) \times N2.$$

By employing *ex ante* equilibrium action from $\Gamma(N1)$ in $\Gamma(N2)$, the ruler secures a higher payoff in $\Gamma(N2)$ than his equilibrium payoff in $\Gamma(N1)$, and Claim 1 is proven. □

STEP 2

Lemma 2: When $P''' \leq 0$ the equilibrium of the game $\hat{\Gamma}$ is unique.

Proof of Lemma 2: When $P''' \leq 0$, the ruler's second order conditions are negative:

$$xP'(\hat{Q}(x))\frac{d^2\hat{Q}(x)}{dx^2} + xP''(\hat{Q}(x))\left[\frac{d\hat{Q}(x)}{dx}\right]^2 + 2P'(\hat{Q}(x))\frac{d\hat{Q}(x)}{dx} < 0 : \forall x \in [0,1],$$

where $\frac{d^2\hat{Q}(x)}{dx^2} < 0$:

$$\frac{d^2\hat{Q}(x)}{dx^2} = \frac{2i}{(1-x)^3 A'(\hat{Q}(x))} + \frac{iA''(\hat{Q}(x))}{(1-x)^2\left[A'(\hat{Q}(x))\right]^2} < 0, \tag{25}$$

because

$$A''(Q) = \frac{1}{N}P'''(Q) + \left[1 - \frac{1}{N}\right]\frac{1}{Q}\left(P''(Q) - \frac{2}{Q}\left[P'(Q) - \frac{P(Q)}{Q}\right]\right) \leq 0,$$

due to

$$P''(Q) - \frac{2}{Q}[P'(Q) - \frac{P(Q)}{Q}] \leq 0 \quad \text{if} \quad P'''(Q) \leq 0. \tag{26}$$

Thus, the ruler's share at which his payoff maximized is unique. Thus, the equilibrium of the game $\hat{\Gamma}$ is unique, and Lemma 2 is proven. □

Claim 2: In the game $\hat{\Gamma}_N$ equilibrium asset value increases with N:

Proof of Claim 2: Assume the reverse: let $\hat{Q}_{N1} > \hat{Q}_{N2}$. Then, $\hat{x}_{N1} < \hat{x}_{N2}$, and there exits $\tilde{x}$ such that in the game $\hat{\Gamma}(N2)$:

$$\hat{q}_{N2}(\tilde{x}) \times N2 = \hat{Q}_{N1},$$

and

$$\hat{x}_{N1} < \tilde{x} < \hat{x}_{N2}. \tag{27}$$

From Theorem 1 and Lemma 2, in the game $\hat{\Gamma}(N2)$:

$$\left.\frac{d\hat{V}(x)}{dx}\right|_{x<\hat{x}_{N2}} > 0, \quad \left.\frac{d\hat{V}(x)}{dx}\right|_{x=\hat{x}_{N2}} = 0, \quad \left.\frac{d\hat{V}(x)}{dx}\right|_{x>\hat{x}_{N2}} < 0,$$

thus, at $x = \tilde{x}$:

(28)

$$\left.\frac{d\hat{V}(x)}{dx}\right|_{x=\tilde{x}} \times \frac{1}{\hat{P}'_{N1}} = x\hat{Q}'(x) + \frac{\hat{P}_{N1}}{\hat{P}'_{N1}} > 0, \quad \text{or} \quad \frac{\tilde{x}}{(1-\tilde{x})^2}\left|\frac{1}{A'_{N2}(Q)}\right| < \frac{\hat{P}_{N1}}{\hat{P}'_{N1}},$$

where equation (13) was used. When $P''' < 0$, from equation (10)

$$A'_{N2}(Q) > A'_{N1}(Q), \tag{29}$$

due to equation (26). Analogously, in the game $\Gamma(N1)$:

$$\left.\frac{d\hat{V}(x)}{dx}\right|_{x=\hat{x}_{N1}} = 0, \quad \text{or} \quad \frac{\hat{x}_{N1}}{(1-\hat{x}_{N1})^2}\left|\frac{1}{A'_{N1}(Q)}\right| = \frac{\hat{P}_{N1}}{\hat{P}'_{N1}},$$

and from equations (27) and (29):

$$\frac{\tilde{x}}{(1-\tilde{x})^2}\left|\frac{1}{A'_{N2}(Q)}\right| > \frac{\hat{x}_{N1}}{(1-\hat{x}_{N1})^2}\left|\frac{1}{A'_{N1}(Q)}\right|,$$

which contradicts equation (28), and Claim 2 is proven. □

Step 3

Consider $Q \in [\bar{Q}, Q_N(0)]$, where $Q_N(0) = q_N(0) \times N$. From the proof of Theorem 1, for any such Q, there exists a unique subgame of the game Γ_N, which starts with x_N, which aggregate equilibrium investment is Q. Let $\mathbf{o}_N(Q)$ denote this equilibrium outcome with actions $(x_N(Q), y_N(Q), \mathbf{q}_N)$, where

$$q_N = Q/N \quad \text{and} \quad q_N = \hat{q}(y_N), \quad q_N = q(x_N(Q)).$$

From our construction and Theorem 1, $y_N(Q)$ is an inverse to $\hat{Q}(y_N)$ and $x_N(Q)$ – to $Q(x_N)$, and the functions y_N and x_N are well-defined for $Q \in$

$[\bar{Q}, Q_N(0)]$.

Claim 3: For N1 < N2 and $Q \in [\bar{Q}, Q_{N1}(0)]$ *we have:*

$$\text{(30)} \qquad \frac{d[x_{N2}(Q) - x_{N1}(Q)]}{dQ} > 0 \quad \text{if} \quad N1 < N2 \quad \text{and} \quad Q \in [\bar{Q}, Q_{N1}(0)].$$

Proof of Claim 3: Since $N1 < N2$, for any fixed $Q \in [\bar{Q}, Q_{N1}(0)]$ we have:

$$x_{N1} < x_{N2} \quad \text{and} \quad y_{N1} < y_{N2}, \text{ or } (1 - y_{N2}(Q)) < (1 - y_{N1}(Q)),$$

and using equations (11) and (29) we get:

$$\left| \frac{dQ_{N1}(x)}{dx} \right|_{x=x_{N1}(Q)} < \left| \frac{dQ_{N2}(x)}{dx} \right|_{x=x_{N2}(Q)},$$

which is the same as equation (30), because it can be written as:

$$\frac{1}{\left| \frac{dQ_{N1}(x)}{dx} \right|_{x=x_{N1}(Q)}} - \frac{1}{\left| \frac{dQ_{N2}(x)}{dx} \right|_{x=x_{N2}(Q)}} > 0,$$

and Claim 3 is proven. □

Step 4

Lemma 4: If the equilibrium outcome $\mathbf{o}^*_N$ *of the game* Γ_N *is static, but is not a commitment outcome, we have:* $Q^*_N = N \times \hat{q}_N(x^*) = \bar{Q}$*, and* x^* *is determined from* $G(x^*) = 0$*, i.e.,* $x^* = \bar{x}$.

Proof of Lemma 4: Follows from the proof of Theorem 1. □

Claim 4: In the game $\Gamma(N)$ aggregate equilibrium investment $Q^* = q^*_N \times N$ *is non-decreasing in* N:

$$\text{(31)} \qquad Q^*_{N1} \leq Q^*_{N2} \quad \text{if} \quad N1 < N2$$

Proof of Claim 4: If the commitment outcomes are sustainable in the games $\Gamma(N1)$ and $\Gamma(N2)$, equation (31) follows from Claim 2. Let the outcomes $\mathbf{o}^*_{N1}$ and $\mathbf{o}^*_{N2}$ with actions $(x^*_{N1}, y^*_{N1}, \mathbf{q}^*_{N1})$ and $(x^*_{N2}, y^*_{N2}, \mathbf{q}^*_{N2})$ be equilibria of the games $\Gamma(N1)$ and $\Gamma(N2)$, and $Q^*_{N1} > Q^*_{N2}$ in violation of equation (31). If both games have *static* equilibria, equation (31) is immediate from Lemma 4. Thus, if $Q^*_{N1} > Q^*_{N2}$ holds, the equilibrium of the game Γ_{N1} is *dynamic*. Let the outcome $\tilde{\mathbf{o}}_{N1}$ with actions $(\tilde{x}_{N1}, \tilde{y}_{N1}, \tilde{\mathbf{q}}_{N1})$ and $\tilde{q}_{N1} = Q^*_{N2}/N1$, and the outcome $\tilde{\mathbf{o}}_{N2}$ with actions $(\tilde{x}_{N2}, \tilde{y}_{N2}, \tilde{\mathbf{q}}_{N2})$ and $\tilde{q}_{N2} = Q^*_{N1}/N2$, denote the equilibria of the subgames of the games $\Gamma(N1)$ and $\Gamma(N2)$ that start with actions $\tilde{x}_{N1}$ and $\tilde{x}_{N2}$, respectively. From Theorem 1, $\tilde{\mathbf{o}}_{N1}$ and $\tilde{\mathbf{o}}_{N2}$ exist and are unique, and:

$$
\begin{aligned}
Q(\tilde{x}_{N1}) = Q^*_{N2} \quad &\text{and} \quad Q(\tilde{x}_{N2}) = Q^*_{N1}, \\
\hat{Q}(\tilde{y}_{N1}) = Q^*_{N2} \quad &\text{and} \quad \hat{Q}(\tilde{y}_{N2}) = Q^*_{N1}, \\
x^*_{N1} < \tilde{x}_{N1} < x^*_{N2} \quad &\text{and} \quad x^*_{N1} < \tilde{x}_{N2} < x^*_{N2}.
\end{aligned}
$$

From our construction:

$$
\begin{aligned}
\tilde{V}_{N2} - V^*_{N1} &= (\tilde{y}_{N1} - y^*_{N1}) \times Q^*_{N1} = (\tilde{x}_{N1} - x^*_{N1}) \times Q^*_{N1}, \\
V^*_{N2} - \tilde{V}_{N1} &= (y^*_{N2} - \tilde{y}_{N1}) \times Q^*_{N1} = (x^*_{N2} - \tilde{x}_{N1}) \times Q^*_{N1},
\end{aligned}
$$

where $\tilde{V}_{N1}$, $\tilde{V}_{N2}$ and V^*_{N1}, V^*_{N2} denote the ruler's payoffs from outcomes $\tilde{\mathbf{o}}_{N1}$, $\tilde{\mathbf{o}}_{N2}$, and $\mathbf{o}^*_{N1}$, $\mathbf{o}^*_{N2}$ in the respective games. From equation (30):

$$
\tilde{V}_{N2} - V^*_{N1} > V^*_{N2} - \tilde{V}_{N1},
$$

because $Q^*_{N1} > Q^*_{N2}$. We rearrange the last equation as:

$$\tilde{V}_{N2} - V^*_{N2} > V^*_{N1} - \tilde{V}_{N1}. \tag{32}$$

Since the ruler's payoff is the highest in equilibrium:

$$V^*_{N1} - \tilde{V}_{N1} > 0,$$

and from equation (32):

$$\tilde{V}_{N2} - V^*_{N2} > 0,$$

which contradicts the assumption that $\mathbf{o}^*_{N2}$ is an equilibrium of the game $\Gamma(N2)$. Thus, equation (31) holds, and Claim 4 and Theorem 4 are proven. □

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