Joint versus Common Ownership of Public Goods [1]

Maija Halonen-Akatwijuka[*] and Evagelos Pafilis[**]

[*] University of Bristol

[**] King's College London

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Abstract

We compare joint and common ownership of public goods in a repeated game. Under common ownership an owner's access to the public good cannot be restricted by other owners while under joint ownership each owner has a veto power. We find that common ownership maximizes the punishment (in the relevant parameter range) while joint ownership minimizes the gain from deviation. Common ownership is optimal when the returns to investments are low consistent with a stylized fact.

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1 Introduction

The celebrated research by Ostrom (1990) finds that repeated games provide powerful insights about management of common pool resources such as grazing areas, forests and irrigation systems. She demonstrates how common ownership has in many cases outperformed both private and public ownership – but in other cases ownership by private firms or government has been successful. Her work is primarily based on case studies. In this paper we take a step toward theoretical comparison of ownership structures by analyzing the ownership of pure public goods in a repeated game.[1]

Property rights theory of Grossman and Hart (1986) and Hart and Moore (1990) – and its extension to public goods by Besley and Ghatak (2001) – is the natural framework for analyzing the various ownership regimes. Baker, Gibbons and Murphy (2002) and Halonen (2002) examine property rights theory in a repeated game for the private goods case. Our contribution is to analyze the ownership of pure public goods in a repeated game. Our analysis can be applied to *provision* of common property regimes, for example maintaining an irrigation system (Ostrom, 1990, 31-32). However, pure public goods model is not applicable to appropriation and potential overuse of common property.

We consider two agents l and h who differ in their valuation for the public good, θ_i, where $\theta_l < \theta_h$. The agents make specific investments, y_i, for example in maintaining the public good. Our interest is in finding the ownership structure that supports first best investments for the lowest discount factor. In the main model we focus on two shared ownership structures, *joint ownership* and *common ownership*, and examine single ownership in an extension. Joint ownership has often been analyzed

[1] E.g. Benhabib and Radner (1992) show how tragedy of commons can be overcome in a repeated game but they do not endogenize the ownership structure. E.g. Copeland and Taylor (2009) examine the strength of property rights in a dynamic model but do not address who should be the owner.

in the property rights framework.[2] Under joint ownership the owners have to reach a unanimous agreement for the project to go ahead. Therefore in the static game the disagreement payoffs are zero and in Nash bargaining the agents split the ex post surplus 50:50 resulting in incentives of $\frac{1}{2}(\theta_l + \theta_h) = c'(y_i)$, where $c'(y_i)$ is the marginal cost of the investment. While common ownership, according to Ostrom and Hess (2010), is an arrangement where an owner's access to the public good cannot be restricted by other owners (but access can be denied for non-owners). Common ownership is a less familiar concept in the property rights framework.[3] Under common ownership there is nothing to bargain about ex post and static incentives are therefore $\theta_i = c'(y_i)$. Clearly the high-valuation agent invests more under common ownership than under joint ownership while the low-valuation agent invests less. Equalizing the incentives under joint ownership is then optimal if the cost function is very convex. We find that for investment cost function $c(y_i) = (y_i)^\gamma$ joint ownership is optimal in the static game for $\gamma > 1.5$.

In the repeated game the incentives depend on the one-shot gain from deviation and on the long-term loss due to punishment for deviation. Joint ownership minimizes the gain from deviation by equalizing the deviation payoffs (which are convex in surplus share). However, common ownership is optimal when the punishment effect is dominant. This is the case when investments are inelastic to surplus share ($\gamma > 2$). As it is difficult to generate punishment, ownership is chosen to maximize punishment power. Common ownership maximizes punishment as for such convex cost function equalizing the investments would be optimal in the static game. When investments

[2] For example in Besley and Ghatak (2001), Halonen (2002), Cai (2003) and Rosenkranz and Schmitz (2003). See Gattai and Natale (2016) for a survey on joint ownership in the property rights theory.

[3] Rosenkranz and Schmitz (2003) call a similar arrangement joint ownership with no veto right. Niedermayer (2013) examines an open source platform where no one can be excluded from the public good. Open source and common ownership are equivalent in a 2-agent setup.

are elastic to surplus share $(\gamma < 2)$, minimizing the gain from deviation provides the best incentives and joint ownership is optimal.

An alternative interpretation of our results is that common ownership is optimal when the returns to investments in the public good are low $(\gamma > 2)$ and joint ownership is optimal when the returns are high $(\gamma < 2)$.[4] Low returns to investments have been identified as a stylized fact of common ownership such as the communal grazing lands in the Swiss Alps (Netting, 1976, 1981, and Ostrom and Hess, 2010). A leading example of joint ownership of a public good, research joint venture, has high returns to investments consistent with our result.[5]

It is interesting to compare our results to the private goods case. In the static game there is a stark contrast between private and public goods. In the private goods case (Grossman and Hart, 1986, Hart and Moore, 1990, and Hart, 1995) ownership is determined by technological factors such as the importance of investment. While Besley and Ghatak (2001) show that for public goods ownership by the high-valuation party provides better incentives than ownership by the low-valuation party irrespective of the importance of investment. In the repeated game the results are more aligned. Halonen (2002) finds that also in the private goods case maximizing punishment is optimal for $\gamma > 2$ and minimizing the gain from deviation is optimal for $\gamma < 2$. However, there are important differences. With private goods the optimal ownership structure of the static game minimizes the gain from deviation while with public goods it is joint ownership (even when it is not optimal in the static game).[6] Furthermore, with public goods the results of the static game, and therefore the punishment maximizing

[4] In an extension we show that these results hold (although with additional conditions) even when we include single ownership in the analysis.

[5] See Caloghirou et al. (2003) for a survey on research joint ventures.

[6] Joint ownership minimizes the gain from deviation in our main model where we compare shared ownership structures. Section 5 qualifies this result when also single ownership is included in the analysis.

structure, depend on γ. This is not the case with the private goods. Also, joint ownership has a different role: with public goods it minimizes the gain from deviation while with private goods it maximizes the punishment. Despite these differences, the cut-off value for γ remains interestingly the same.

In the main model we apply trigger strategies. In an extension we examine renegotiation by allowing the deviator to pay a monetary transfer to the other party to restore ex post efficiency.[7] This modelling approach fits well in many common property arrangements where offenders have to pay a fine (Ostrom, 1990, p. 98). We show that, as in the private goods case of Blonski and Spagnolo (2007), renegotiation does not change the optimal ownership structure because the monetary transfer is set so high that all the gains from renegotiation go to the non-defecting party. Therefore the continuation payoff for the deviating party is equal to his continuation payoff without any renegotiation, that is his payoff with trigger strategy.

In this paper we extend the analysis of ownership of public goods by Besley and Ghatak (2001) to a repeated game. Their work has also been extended to e.g. impure public goods (Francesconi and Muthoo, 2011), indispensable agents (Halonen-Akatwijuka, 2012), generalized Nash bargaining solution (Schmitz, 2013) and the location of public good (Halonen-Akatwijuka and Pafilis, 2014). None of these papers provide dynamic analysis.

Rosenkranz and Schmitz (2003) and Niedermayer (2013) also compare common ownership and joint ownership (in addition to proprietary ownership) – although they use different terminology.[8] In the private goods framework of Rosenkranz and Schmitz (2003), joint ownership induces knowledge disclosure while common ownership pro-

[7] See e.g. Levin (2003) and Goldlücke and Kranz (2012) on repeated games with monetary transfers and e.g. Doornik (2006) and Rayo (2007) on their applications in organizations.

[8] Our joint ownership is equivalent to joint ownership with bilateral veto power in Rosenkranz and Schmitz (2003) and to standardized platform in Niedermayer (2013). See footnote 3 for common ownership.

vides good investment incentives. In Niedermayer (2013) there is a public good (platform) but only one agent makes an investment in the public good. The agents additionally invest in private goods (applications) complementary to the platform. Common ownership provides good incentives to invest in the applications while under joint ownership the investment in the platform internalizes some of the positive externality on the second application. Neither paper analyzes a repeated game.

The incomplete contracting literature on privatization (e.g. Hart et al., 1997 and Hoppe and Schmitz, 2010) and on public-private partnerships (e.g. Hart, 2003, Bennett and Iossa, 2006, Martimort and Poyet, 2008, and Chen and Chiu, 2010) are related. We differ in allowing also the private providers to be value driven and modelling explicitly the public good nature of the projects. This literature does not provide dynamic analysis either.

The rest of the paper is organized as follows. Section 2 presents the static game and Section 3 analyzes the repeated game. Section 4 compares the results of the repeated game for public and private goods. Section 5 extends the analysis to single ownership and Section 6 examines renegotiation. Section 7 concludes.

2 Static game

There are two players, l and h. Each agent makes a project-specific investment denoted by y_l and y_h.[9] Public good is produced and the benefit from the project is equal to $(y_l + y_h)$. The players value the project differently: the low-valuation agent's utility from the public good is $\theta_l(y_l + y_h)$ and the high-valuation agent's utility is $\theta_h(y_l + y_h)$ where $\theta_l < \theta_h$. Investment costs are given by $c(y_i) = (y_i)^\gamma$ for $i = l, h$ where $\gamma > 1$.

[9] In the main model the investment can be in either human or physical capital. In Section 5 the nature of the investment will matter.

Joint surplus is equal to $S = (\theta_l + \theta_h)(y_l + y_h) - c(y_l) - c(y_h)$. The first-best investments are then given by the following first-order conditions

$$(\theta_l + \theta_h) = c'(y_i^*) \text{ for } i = l, h. \tag{1}$$

We denote $y^* \equiv y_1^* = y_2^*$.

Contracts are incomplete. Therefore ex ante contracts can only be written on the ownership of the public good. In the main model we focus on two types of shared ownership, *joint ownership* and *common ownership*, and leave the analysis of single ownership to Section 5. Under joint ownership a unanimous agreement by the owners is required for the project to go ahead. Under common ownership, according to Ostrom and Hess (2010), an owner's access to the public good cannot be restricted by other owners although access can be denied for non-owners.

The timing is the following:

Stage 1. l and h contract on the ownership of the project. We analyze joint ownership and common ownership.

Stage 2. l and h invest in project-specific capital.

Stage 3. l and h bargain over the completion of the project and produce the public good.

Under joint ownership the disagreement payoffs are zero as each agent has veto power. Therefore the agents split the ex post surplus 50:50 in Nash bargaining leading to the following payoffs

$$u_i^J = \frac{1}{2}(\theta_l + \theta_h)(y_h + y_l) - c(y_i) \quad \text{for } i = l, h \tag{2}$$

where superscript J denotes joint ownership. Under joint ownership the incentives are

$$\frac{1}{2}(\theta_l + \theta_h) = c'\left(y_i^J\right). \tag{3}$$

We denote $y^J \equiv y_1^J = y_2^J$.

Under common ownership neither consumption of the public good nor participation in its production can be restricted for the owners. Therefore there is nothing to bargain about in stage 3. The payoffs are

$$u_i^C = \theta_i(y_l + y_h) - c(y_i) \quad i = l, h. \tag{4}$$

Common ownership is denoted by superscript C. Optimal investments under common ownership, denoted by y_i^C, are given by

$$\theta_i = c'\left(y_i^C\right) \quad i = l, h. \tag{5}$$

Equations (1), (3) and (5) show that $y_l^C < y^J < y_h^C < y^*$. Proposition 1 compares the joint surplus under common ownership and joint ownership.

Proposition 1 *In the static game joint ownership dominates common ownership if and only if* $\gamma > 1.5$.

All the proofs are in Appendix A.1.

Under joint ownership both agents have equal, intermediate incentives. While under common ownership the high-valuation agent has strong incentives and the low-valuation agent has weak incentives. Now if γ is high enough, two intermediate investments are more cost-effective than one high and one low investment and joint ownership is optimal.

3 Repeated game

In a repeated game the agents can support the first-best investments if they are sufficiently patient. Our interest is in finding the ownership structure that sustains the first-best investments for the greatest range of discount factors. In this Section we focus on trigger strategies with reversion to the Nash equilibrium of the static game as punishment. In Section 6 we introduce renegotiation.

The agents implicitly agree to make the efficient investments, y^*, and agent h agrees to pay l a transfer T^* which is such that the incentive compatibility constraints are satisfied. Cooperation is maintained as long as both agents follow the efficient behavior. Any deviation triggers punishment for the rest of the game.

First best will be supported if and only if the discounted payoff stream from efficient behavior exceeds the payoff stream from deviation for both agents. The incentive compatibility constraints are

$$\frac{1}{1-\delta}\left[2\theta_h y^* - T - c\left(y^*\right)\right] \geq P_h^{d,\omega} + \frac{\delta}{1-\delta} P_h^{p,\omega} \tag{6}$$

$$\frac{1}{1-\delta}\left[2\theta_l y^* + T - c\left(y^*\right)\right] \geq P_l^{d,\omega} + \frac{\delta}{1-\delta} P_l^{p,\omega} \tag{7}$$

where δ is the discount factor, $P_i^{d,\omega}$ is i's one-shot deviation payoff under ownership structure ω and $P_i^{p,\omega}$ is i's payoff in the punishment path. $P_i^{p,\omega}$ is obtained by substituting the optimal investments of the static game (given by equation (3) or (5)) in agent i's payoff function (equation (2) or (4)). $P_i^{d,\omega}$ differs from $P_i^{p,\omega}$ in that $y_j = y^*$ is substituted in.

The agents can find a suitable T that satisfies both agents' incentive compatibility constraints as long as the aggregate incentive compatibility constraint is satisfied.

Summing up (6) and (7) we find that first-best investments can be sustained in equilibrium if and only if

$$\delta \geq \frac{G^{\omega}}{G^{\omega}+L^{\omega}} \equiv \underline{\delta}^{\omega}. \tag{8}$$

$G^{\omega} = \left(P_h^{d,\omega} + P_l^{d,\omega} - S^*\right)$ is the gain from deviation and $L^{\omega} = (S^* - S^{p,\omega})$ is the loss from deviation, where S^* is the first-best joint surplus and $S^{p,\omega}$ is the joint surplus in the punishment path. If the discount factor is high enough, the one-shot gain from deviation is outweighed by the long-term punishment. Our aim is to find an ownership structure which minimizes $\underline{\delta}^{\omega}$.

It is useful to first examine the gain and the loss from deviation.

Proposition 2 (i) *The gain from deviation is lower under joint ownership than under common ownership.*

(ii) *The loss from deviation is higher under joint ownership than under common ownership if and only if* $\gamma < 1.5$.

Proposition 2(i) can be understood as follows. The deviation payoffs under common ownership are

$$P_h^{d,C} = \theta_h \left(y^* + y_h^C\right) - c\left(y_h^C\right) \tag{9}$$

$$P_l^{d,C} = \theta_l \left(y_l^C + y^*\right) - c\left(y_l^C\right) \tag{10}$$

and under joint ownership

$$P_i^{d,J} = \frac{1}{2}\left(\theta_l + \theta_h\right)\left(y^* + y^J\right) - c\left(y^J\right). \tag{11}$$

There are two sources to the gain from deviation. The first part comes from the ability to expropriate from the other agent's first-best investment. Under joint ownership the agents can expropriate half of the *joint* value of the other agent's first-best investment

($\frac{1}{2}(\theta_l+\theta_h)\,y^*$ in equation (11)) while under common ownership they can expropriate the full *individual* value ($\theta_h y^*$ in equation (9) or $\theta_l y^*$ in equation (10)). However, adding these up amounts to $(\theta_l+\theta_h)\,y^*$ under both ownership structures. Therefore the difference in the gain from deviation comes from the second source, the payoff earned from the agent's own second-best investment. This can be seen from the following equation (which is derived in the Appendix and does not depend on y^*).

$$G^C - G^J = \left[\theta_h y_h^C - c\left(y_h^C\right)\right] + \left[\theta_l y_l^C - c\left(y_l^C\right)\right] - 2\left[\frac{1}{2}(\theta_l+\theta_h)\,y^J - c\left(y^J\right)\right] \qquad (12)$$

When $\theta_l = \theta_h$ the ownership structures are equivalent (see equations (3) and (5)) and $G^C = G^J$. Using the envelope theorem we can show that

$$\frac{\partial\left(G^C - G^J\right)}{\partial\theta_h} = y_h^C - y^J > 0 \qquad (13)$$

and therefore $G^C > G^J$ for any $\theta_l < \theta_h$.

Agent i's payoff from his own investment is $\sigma y_i - c(y_i)$, where σ denotes the share of the value of his own investment that an agent obtains in bargaining. We can show that this payoff is convex in σ.[10] That is why equalizing the deviation payoffs under joint ownership minimizes them compared to a significantly higher payoff for h and a moderately lower payoff for l under common ownership.

Proposition 2(ii) is the mirror image of Proposition 1(ii). Since the joint surplus is higher in the static game under common ownership for $\gamma < 1.5$, joint ownership maximizes the punishment in this parameter range.

Proposition 2 shows that for $\gamma < 1.5$ joint ownership provides both the maximal punishment and the minimal gain from deviation. Then joint ownership provides better incentives for cooperation unambiguously. While for higher values of γ there is

[10] $\sigma y_i - c(y_i) = \sigma(\sigma/\gamma)^{1/(\gamma-1)} - (\sigma/\gamma)^{\gamma/(\gamma-1)} = (\gamma-1)(\sigma/\gamma)^{\gamma/(\gamma-1)}$.

a trade-off: joint ownership minimizes the gain but also minimizes the punishment.

Proposition 3 *In the repeated game common ownership dominates joint ownership if and only if* $\gamma > 2$.

Proposition 3 shows that common ownership is optimal for $\gamma > 2$. In this parameter range common ownership maximizes the punishment although that comes at the cost of maximal gain from deviation. The results depend on the elasticity of investment to surplus share. This elasticity determines how much the surplus drops along the punishment path and is equal to $1/(\gamma - 1)$.[11] Therefore the investment is inelastic (elastic) when $\gamma > 2$ ($\gamma < 2$). When the investment is inelastic, the surplus does not fall much after deviation. Then the ownership structure has to be chosen to maximize the punishment and common ownership is optimal. When the investment is elastic, either ownership structure provides enough punishment power and minimizing the gain from deviation provides the best incentives for cooperation. Then joint ownership is optimal. We will discuss the relationship of these results to the private goods case of Halonen (2002) in Section 4.

We can also compare the emergence of joint ownership in the static and in the repeated game. In the static game joint ownership dominates when equalizing the agents' investments is cost-effective ($\gamma > 1.5$). In the repeated game joint ownership emerges when it is optimal to minimize the gain from deviation by equalizing the deviation payoffs ($\gamma < 2$). Interestingly, the parameter ranges are partially overlapping and for $1.5 < \gamma < 2$ joint ownership is optimal both in the static and in the repeated game.

We have shown that common ownership is optimal when the investments are inelastic to surplus share. Alternatively, we can say that there are low returns to

[11] Agent's optimal investment in the static game is $y = (\sigma/\gamma)^{1/(\gamma-1)}$. The elasticity of investment to surplus share is given by $(\partial y/\partial\sigma)(\sigma/y) = 1/(\gamma - 1)$.

investments when $\gamma > 2$. Low returns to investments have been identified as a stylized fact of common ownership (Netting, 1976, 1981, and Ostrom and Hess, 2010). An example is the use of Alpine hillsides for communal grazing lands in Switzerland. Joint ownership is optimal when the investments are productive $(\gamma < 2)$. Horizontal research joint venture (RJV) is a leading example of joint ownership of a public good.[12] Returns to investments are high(er) consistent with our result.[13]

4 Public vs. private goods

In this section we compare the results of the repeated game for public and private goods, the latter analyzed in Halonen (2002). Interestingly, the results of the private goods case also depend on whether γ is greater or smaller than 2. However, there are several differences in the effects.

With private goods the optimal ownership structure of the static game provides the best incentives when $\gamma < 2$ because it minimizes the gain from deviation. While for $\gamma > 2$ the worst ownership structure of the static game (joint ownership in the private goods case) is optimal because the punishment is maximized. With public goods the results no longer depend on the tradeoff between the best and the worst ownership structure of the static game. However, minimizing the gain from deviation continues to be optimal when the investments are elastic. But now joint ownership minimizes the gain from deviation even when it is not optimal in the static game. Similarly, maximizing the punishment is optimal when the investments are inelastic. But now also the results of the static game depend on γ and that gives a new twist. In this parameter range common ownership provides the largest punishment because for large

[12] In a horizontal RJV any innovation becomes a public good for the partners. While a private good model is appropriate for a vertical RJV where an inventor and a developer cooperate and only the developer can commercialize the innovation.

[13] See e.g. Hagedoorn (1996) and (2002) for evidence.

γ equalizing investments by joint ownership is cost-efficient in the static game.

Note also that joint ownership has a different role depending on the nature of goods. Joint ownership minimizes the gain from deviation with public goods and maximizes the punishment with private goods.[14] The final difference is that in the private goods case there is always a trade-off between maximizing punishment and minimizing the gain from deviation. With public goods there is a parameter range for which joint ownership provides both minimal gain and maximal punishment. Despite these differences, the cut-off value for γ is the same. This is particularly interesting as the results of the static game differ significantly. In the private goods case (Grossman and Hart, 1986, Hart and Moore, 1990, Hart, 1995) it is optimal to concentrate ownership in the hands of the agent with an important investment. To the contrary, Besley and Ghatak (2001) show that the high-valuation agent should own the public good even when only the low-valuation agent has an investment.

We can now continue the common ownership example of Alpine grazing lands. More productive agricultural lands in the mountain valleys are privately owned, that is private goods (Netting 1976, 1981). Our model takes it as given that the good is public and derives the optimal owner for the public good. However, land can remain as a public good or can be fenced to be a private good. According to Halonen (2002) single ownership is optimal for private goods when $\gamma < 2$. Private ownership of productive agricultural lands is therefore consistent with this result.

5 Single ownership

In the main model we compared ownership structures with two owners. We now examine an ownership structure where either agent l or agent h is the single owner.

[14] Therefore our results of the public goods case are opposite to the private goods case where joint ownership is optimal for $\gamma > 2$.

We assume that under single ownership, if bargaining breaks down and the agents cannot collaborate, proportion μ of the non-owner's investment remains in the project, where $0 \leq \mu \leq 1$. Therefore agent k's disagreement payoff under ownership by i is $\theta_k (y_i + \mu y_j)$, where $k, i, j = l, h$ and $i \neq j$.[15]

Nash bargaining payoffs under ownership by agent i are

$$\begin{aligned} u_i^i &= \theta_i (\mu y_j + y_i) + \frac{1}{2} (\theta_l + \theta_h)(1 - \mu) y_j - c(y_i) \\ &= \frac{1}{2} (\theta_l + \theta_h)(y_i + y_j) + \frac{1}{2} (\theta_i - \theta_j)(y_i + \mu y_j) - c(y_i), \end{aligned} \tag{14}$$

$$u_j^i = \frac{1}{2} (\theta_l + \theta_h)(y_i + y_j) + \frac{1}{2} (\theta_j - \theta_i)(y_i + \mu y_j) - c(y_j). \tag{15}$$

The first term in (14) and (15) shows the holdup problem. The second term arises from the default payoffs. Agent h's higher valuation for the public good implies that his default payoff is larger improving his relative bargaining position. That is why the second term is positive for agent h and negative for agent l.

Investment incentives in the static game are

$$\theta_i = c'\left(y_i^i\right), \tag{16}$$

$$\frac{1}{2} (\theta_l + \theta_h) + \frac{1}{2} (\theta_j - \theta_i) \mu = c'\left(y_j^i\right). \tag{17}$$

Note that common ownership is formally equivalent to single ownership with $\mu = 1$. In both cases both agents' investments fully contribute to the value of the project even

[15] Now, unlike in the main model, it becomes important whether the investment is in physical or human capital. Investment in physical capital remains in the project if the investing agent leaves and $\mu = 1$. Investment in human capital is embedded in the person although some of it may spill over to the project and $0 \leq \mu \leq 1$.

under disagreement – either because the access of common owners cannot be restricted or because the non-owner's investment is fully sunk in the project.

It follows from (3), (5), (16) and (17) that for $0 \leq \mu < 1$

$$y_l^C = y_l^l < y_l^h \leq y^J < y^*, \tag{18}$$

$$y^J \leq y_h^l < y_h^C = y_h^h < y^*. \tag{19}$$

Equations (18) and (19) firstly replicate the main result of Besley and Ghatak (2001): h-ownership provides better incentives for *both* agents than l-ownership. Secondly, h-ownership dominates common ownership and a repeated game is needed to provide a rationale for common ownership.[16]

As previously, let us proceed to analyze the gain and loss from deviation.

Proposition 4 *Assume* $\mu < 1$.

(i) $\max\left\{G^J, G^h\right\} < G^C < G^l$,

(ii) $\max\left\{L^J, L^h\right\} < L^C < L^l$ *if and only if* $\gamma > 1.5$.

(iii) $L^h < L^C < \min\left\{L^J, L^l\right\}$ *if and only if* $\gamma < 1.5$.

Proposition 4 shows that there are broadly two classes of ownership structures. First, the ownership structures that can be optimal in the static game – joint ownership and h-ownership – minimize the gain from deviation. Second, the ownership structures that are dominated in the static game – common ownership and l-ownership – maximize the punishment in the parameter range where the punishment effect is important. In line with the previous results, we will show that common ownership or l-ownership is optimal if $\gamma > 2$ while joint ownership or h-ownership is optimal if $\gamma < 2$.

[16] It is easy to show that joint ownership is optimal in the static game if and only if $\gamma > 1.5$ and $\mu \geq \widetilde{\mu}$, where $0 < \widetilde{\mu} < 1$, and h-ownership is optimal otherwise.

Proposition 4 also shows that joint ownership still provides both large punishment and small gain from deviation if $\gamma < 1.5$.

Proposition 5 derives the optimal ownership structure.

Proposition 5 *In the repeated game*

(i) joint ownership is optimal if $\gamma < 2$ *and* $\mu \to 1$,

(ii) ownership by the high-valuation agent is optimal if $\gamma < 2$ *and* $\mu \to 0$,

(iii) common ownership is optimal if $\gamma > 2$ *and* $\frac{\theta_l}{\theta_h} \to 0$ *and*

(iv) ownership by the low-valuation agent is optimal if $\gamma > 2$, $\frac{\theta_l}{\theta_h} \to 1$ *and* $\mu \to 0$.

Proposition 5 shows that also single ownership can emerge as optimal in the repeated game. In the parameter range where the gain effect is important $(\gamma < 2)$, h-ownership is optimal for small μ because it minimizes the gain from deviation. Agent h's deviation payoff under h-ownership is

$$P_h^{d,h} = \frac{1}{2}(\theta_h + \theta_l)\left(y_h^h + y^*\right) + \frac{1}{2}(\theta_h - \theta_l)\left(y_h^h + \mu y^*\right) - c\left(y_h^h\right). \tag{20}$$

When agent l's first best investment is largely embedded in himself $(\mu \to 0)$, h's ability to extract from it is limited.[17] While for high values of μ the gain from deviation under joint ownership (which does not depend on μ) is lower than the gain under h-ownership (which is increasing in μ) and joint ownership is optimal.

In the parameter range where the punishment effect is dominant $(\gamma > 2)$, ownership by the low-valuation agent can be optimal but only if θ_l is not too low compared to θ_h. Here the effects are more subtle as the optimal ownership structure does not simply maximize the punishment ($L^l > L^C$ and $G^l > G^C$ for all parameter values). The

[17] Note that for agent l there is the opposite effect $\left(\partial P_l^{d,h}/\partial\mu < 0\right)$ but it is of a smaller magnitude so that $\partial G^h/\partial\mu > 0$ (as verified by equation (50)).

difference between agent l's punishment payoffs is equal to

$$P_l^{p,l} - P_l^{p,C} = \frac{1}{2}\left[(\theta_h + \theta_l) + (\theta_l - \theta_h)\mu\right] y_h^l - \theta_l y_h^C.$$

(Remember that $y_l^l = y_l^C$.) $\partial\left(P_l^{p,l} - P_l^{p,C}\right)/\partial\theta_l < 0$ and therefore lower θ_l decreases l's punishment payoff more under common ownership than under l-ownership. Therefore the loss from deviation increases more under common ownership when $\frac{\theta_l}{\theta_h} \to 0$ and common ownership is optimal. While l-ownership emerges as optimal when the (marginal) gain effect is dominant. The difference between agent l's deviation payoffs is equal to

$$P_l^{d,l} - P_l^{d,C} = \frac{1}{2}(\theta_h - \theta_l)(1-\mu) y^*.$$

$\partial\left(P_l^{d,l} - P_l^{d,C}\right)/\partial\theta_l < 0$ and therefore higher θ_l increases l's deviation payoff – and the aggregate gain from deviation – more under common ownership favouring l-ownership.[18] That is why l-ownership is optimal for $\frac{\theta_l}{\theta_h} \to 1$.

Figure 1 presents simulation results which show that the results of Proposition 5 hold also for intermediate values of μ and $\frac{\theta_l}{\theta_h}$.[19] For $\gamma < 2$ h-ownership is optimal for low values of μ and joint ownership for high values of μ. While for $\gamma > 2$ the optimal ownership structure is common ownership for low values of $\frac{\theta_l}{\theta_h}$ and l-ownership for high values of $\frac{\theta_l}{\theta_h}$.[20]

[18]Note also that $\partial^2\left(P_l^{p,l} - P_l^{p,C}\right)/\partial(\theta_l)^2 > 0$ and $\partial^2\left(P_l^{d,l} - P_l^{d,C}\right)/\partial(\theta_l)^2 < 0$ which explains why the marginal loss effect is dominant for low θ_l and the marginal gain effect is dominant for high θ_l.

[19]Figure 1(a) is drawn for small $\frac{\theta_l}{\theta_h}$ so that common ownership is optimal for all μ if $\gamma > 2$. Figure 1(b) is drawn for small μ so that h-ownership is optimal for all $\frac{\theta_l}{\theta_h}$ if $\gamma < 2$.

[20]Simulation results also show that $\mu \to 0$ is not a necessary condition for l-ownership to be optimal (Proposition 5(iv)).

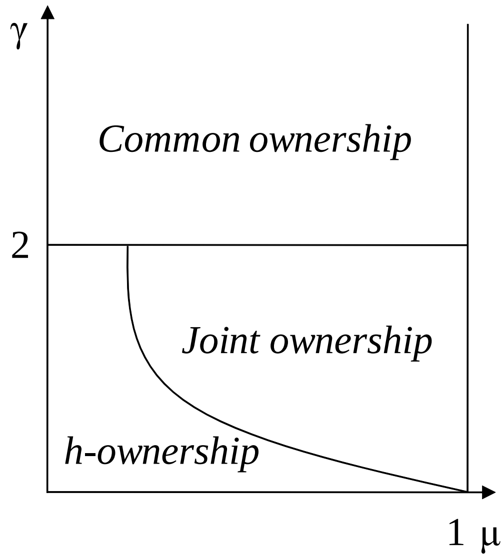

Figure 1(a)

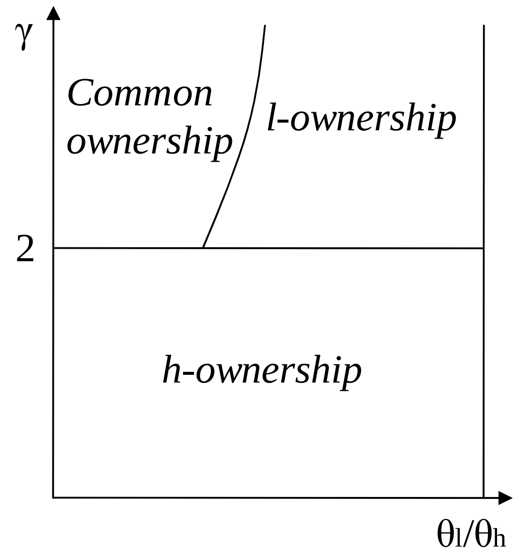

Figure 1(b)

Even when we include single ownership in the analysis, common ownership continues to be optimal in the relevant case of low returns to investments – as long as the agents' valuations of the public good are not too homogeneous. The additional condition requires further discussion. In the empirical literature there is no consensus on the role of heterogeneity in the management of common-pool resources (see e.g. Poteete and Ostrom, 2004, and Ruttan, 2006, 2008). Different types of heterogeneity can have different effects. For example, economic inequality may have a positive effect[21] while socio-cultural heterogeneity has a more negative effect. In our model the agents differ only in the valuation of the public good. The valuation difference can arise from economic inequality (e.g. the value of irrigation system depends on

[21] See also Baland and Platteau (2003) for theoretical analysis where the effect of income inequality depends on the model setup.

the agent's land endowment)[22] and therefore our result is not inconsistent with the empirical results.[23]

Joint ownership also remains optimal for high returns to investments. The additional requirement is that the investments are largely sunk in the project.[24] This matches well with R&D since innovation can typically be commercialized without the presence of the other party.

6 Renegotiation

We have applied trigger strategies and assumed that the ownership structure cannot be renegotiated in the punishment path. We will now introduce renegotiation and allow the deviator to pay a monetary transfer to the other agent to restore cooperation. This is a natural way to model renegotiation as in many common property arrangements offenders pay a fine (Ostrom, 1990, p. 98).[25] Our analysis draws on Blonski and Spagnolo (2007) who examine renegotiation in the private goods case. In what follows, we show that our results are robust to introducing renegotiation and fines.

The agents' strategies are the following.

Phase 1: invest y^* and pay (or receive) T^*. If agent i deviates, start Phase 2.

Phase 2:

Agent $j \neq i$: If agent i pays transfer $F^{i,\omega}$ at the beginning of the period, go back to Phase 1.

[22] Also cultural view of the resource can affect its valuation. However, cultural differences also affect importantly the process of building trust.

[23] Note also that the empirical literature focuses mainly on appropriation while we analyse provision of common property regimes.

[24] Note that this 'internal' spillover is different from R&D spillover which usually refers to unintended leaking of knowledge to rivals.

[25] Fines are often graduated. First-time offenders may pay an insignificant fine but for repeat offenders the punishment gradually increases all the way to banishment (Ostrom, 1990, p. 98.) Our analysis focuses on the maximal fine.

Otherwise, choose y_j^{ω} and start Phase 2 in the next period.

Agent i : Pay $F^{i,\omega}$ to agent j and go back to Phase 1.

If any player deviates in Phase 2, re-start Phase 2 against that player.

After deviating in investment, agent i can restore cooperation by paying a transfer $F^{i,\omega}$ to agent j at the beginning of the following period. If agent i does not pay $F^{i,\omega}$, then agent j will choose punishment investment y_j^{ω} in that period. We take the position that the agents would not engage in punishing the deviator by lower investment than the optimal investment of the static game, y_j^{ω}, as that would harm the public good.[26] (In Appendix A.2 we examine lower punishment investments.[27])

Suppose agent h has deviated. The incentive compatibility constraint for paying the transfer $F^{h,\omega}$ is

$$-F^{h,\omega}+\frac{1}{1-\delta}\left[2\theta_h y^* - c\left(y^*\right) - T^*\right] \geq P_h^{p,\omega}+\delta\left\{-F^{h,\omega}+\frac{1}{1-\delta}\left[2\theta_h y^* - c\left(y^*\right) - T^*\right]\right\}. \tag{21}$$

If agent h pays $F^{h,\omega}$, cooperation is restored immediately. Otherwise, agent h earns his static payoff $P_h^{p,\omega}$ and, using the one-shot deviation principle, the restoration of cooperation is postponed by one period. From equation (21) we can solve for the maximum transfer that agent h would be willing to pay and we set $F^{h,\omega}$ at its maximum value.

$$F^{h,\omega}=\frac{\left[2\theta_h y^* - c\left(y^*\right) - T^*\right] - P_h^{p,\omega}}{(1-\delta)} \tag{22}$$

In a similar manner we can derive $F^{l,\omega}$.

$$F^{l,\omega}=\frac{\left[2\theta_l y^* - c\left(y^*\right) + T^*\right] - P_l^{p,\omega}}{(1-\delta)} \tag{23}$$

[26] For example if the investment is in maintaining the public good, a very low punishment investment could irreversibly damage the public good.

[27] In the Appendix we show that if it is reasonable to assume that the agents punish by zero investments, then joint ownership is optimal.

The incentive compatibility constraints for investing y^* are now

$$\frac{1}{1-\delta}\left[2\theta_h y^* - c\left(y^*\right) - T^*\right] \geq P_h^{d,\omega} + \delta\left\{-F^{h,\omega} + \frac{1}{1-\delta}\left[2\theta_h y^* - c\left(y^*\right) - T^*\right]\right\}, \quad (24)$$

$$\frac{1}{1-\delta}\left[2\theta_l y^* - c\left(y^*\right) + T^*\right] \geq P_l^{d,\omega} + \delta\left\{-F^{l,\omega} + \frac{1}{1-\delta}\left[2\theta_l y^* - c\left(y^*\right) + T^*\right]\right\}. \quad (25)$$

Summing up equations (24) and (25) we obtain the aggregate incentive compatibility constraint

$$\delta\left(F^{h,\omega} + F^{l,\omega}\right) \geq P_h^{d,\omega} + P_l^{d,\omega} - S^*. \quad (26)$$

And finally substituting equations (22) and (23) in (26) we obtain the critical discount factor

$$\delta \geq \frac{P_h^{d,\omega} + P_l^{d,\omega} - S^*}{P_h^{d,\omega} + P_l^{d,\omega} - S^{p,\omega}}. \quad (27)$$

Equation (27) is equivalent to equation (8) and therefore introducing renegotiation does not change our previous results. This is because all the surplus from renegotiation goes to the non-defecting party. Therefore the deviator's continuation payoff is equal to his continuation payoff without renegotiation, that is his payoff with trigger strategy. Note also that renegotiation of ownership structure after deviation is not optimal since the payment of the transfer restores ex post efficiency.

7 Conclusions

In this paper we have focused on shared ownership of public goods, in particular common ownership. In the property rights theory common ownership cannot be optimal in the static game[28] while our repeated game can provide a rationale for it. Insights from repeated games have indeed been used to understand successful management of common pool resources (Ostrom, 1990). Common ownership is, however, not a panacea and therefore we need to compare it to other ownership structures. To the best of our knowledge, this has not been done previously in a repeated game. We find that common ownership, as compared to joint ownership, has the benefit of maximizing the punishment (in the relevant parameter range) but it comes at the cost of maximizing the gain from deviation. Common ownership is optimal if the investments in the public good are inelastic to surplus share. Alternatively, we can say that common ownership is optimal if the returns to investments are low which is consistent with a stylized fact. In our analysis the optimal ownership structure sustains the first-best investments for the lowest discount factor. It is further interesting that the critical discount factor is the lowest exactly when common ownership is optimal ($\underline{\delta} < 1/2$ if and only if $\gamma > 2$)[29].

Our analysis of pure public goods applies to provision of common property regimes. An important direction for future work is to extend the analysis to common pool resources which are similar to pure public goods in the difficulty of excluding beneficiaries but differ in the possibility of overuse.

[28] Common ownership is dominated by h-ownership in the static game. In Niedermayer (2013) common ownership can be optimal in the static game but the model setup is specific to platforms. Common ownership gives the worst incentives for investing in the public good (platform) but can be optimal because of its effect on the investments in the (private) applications. In Rosenkranz and Schmitz (2003) common ownership can be optimal in a 2-stage game but their model is essentially a private goods model where each agent invests in their own project but there can be knowledge spillovers.

[29] This holds for all the ownership structures according to simulations.

A Appendix

A.1 Proofs

Firstly we give the explicit forms of the investments derived from (1) , (3) and (5).

$$y^* = \left(\frac{\theta_l + \theta_h}{\gamma}\right)^{\frac{1}{\gamma-1}} \tag{28}$$

$$y^J = \left(\frac{\theta_l + \theta_h}{2\gamma}\right)^{\frac{1}{\gamma-1}} \tag{29}$$

$$y_l^C = \left(\frac{\theta_l}{\gamma}\right)^{\frac{1}{\gamma-1}} \tag{30}$$

$$y_h^C = \left(\frac{\theta_h}{\gamma}\right)^{\frac{1}{\gamma-1}} \tag{31}$$

Proof of Proposition 1.

Joint surplus under joint ownership is larger than under common ownership if and only if

$$2(\theta_l + \theta_h) y^J - 2c\left(y^J\right) > (\theta_l + \theta_h)\left(y_l^C + y_h^C\right) - c\left(y_l^C\right) - c\left(y_h^C\right). \tag{32}$$

Define $\theta_h = \alpha\theta_l$, where $\alpha > 1$. Substituting this definition and equations (29) – (31) in (32) we obtain

$$2(\alpha+1)\theta_l\left(\frac{(\alpha+1)\theta_l}{2\gamma}\right)^{\frac{1}{\gamma-1}} - 2\left(\frac{(\alpha+1)\theta_l}{2\gamma}\right)^{\frac{\gamma}{\gamma-1}} >$$

$$(\alpha+1)\,\theta_l\left[\left(\frac{\alpha\theta_l}{\gamma}\right)^{\frac{1}{\gamma-1}}+\left(\frac{\theta_l}{\gamma}\right)^{\frac{1}{\gamma-1}}\right]-\left(\frac{\alpha\theta_l}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}-\left(\frac{\theta_l}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}$$

which is equivalent to

$$2\,(\alpha+1)\left(\frac{\alpha+1}{2\gamma}\right)^{\frac{1}{\gamma-1}}-2\left(\frac{\alpha+1}{2\gamma}\right)^{\frac{\gamma}{\gamma-1}}>$$

$$(\alpha+1)\left[\left(\frac{\alpha}{\gamma}\right)^{\frac{1}{\gamma-1}}+\left(\frac{1}{\gamma}\right)^{\frac{1}{\gamma-1}}\right]-\left(\frac{\alpha}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}-\left(\frac{1}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}. \tag{33}$$

In Supplementary Appendix 1.1 we show that (33) is equivalent to

$$\psi_s\,(\alpha,\gamma)>\chi_s\,(\alpha,\gamma)$$

where

$$\psi_s\,(\alpha,\gamma)=\frac{2\gamma-1}{\gamma}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}(\alpha+1)^{\frac{\gamma}{\gamma-1}}-(\alpha+1)\,\alpha^{\frac{1}{\gamma-1}}+\frac{1}{\gamma}\alpha^{\frac{\gamma}{\gamma-1}},$$

$$\chi_s\,(\alpha,\gamma)=(\alpha+1)-\frac{1}{\gamma}.$$

Subscript s denotes static game.

Differentiating $\psi_s\,(\alpha,\gamma)$ with respect to α gives

$$\frac{\partial\psi_s\,(\alpha,\gamma)}{\partial\alpha}=\frac{2\gamma-1}{\gamma-1}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}(\alpha+1)^{\frac{1}{\gamma-1}}-\alpha^{\frac{1}{\gamma-1}}-\frac{1}{\gamma-1}\alpha^{\frac{2-\gamma}{\gamma-1}}.$$

Note that $\psi_s\,(1,\gamma)=\chi_s\,(1,\gamma)=\frac{2\gamma-1}{\gamma}$ and $\frac{\partial\psi_s(\alpha,\gamma)}{\partial\alpha}|_{\alpha=1}=\frac{\partial\chi_s(\alpha,\gamma)}{\partial\alpha}|_{\alpha=1}=1$. Since $\psi_s\,(\alpha,\gamma)$ and $\chi_s\,(\alpha,\gamma)$ are tangent at $\alpha=1$ and $\chi_s\,(\alpha,\gamma)$ is linear and increasing in α, $\psi_s\,(\alpha,\gamma)\geq\chi_s\,(\alpha,\gamma)$ if $\partial^2\psi_s\,(\alpha,\gamma)\,/\partial\alpha^2>0$. The rest of the proof establishes that $\partial^2\psi_s\,(\alpha,\gamma)\,/\partial\alpha^2>0$ for any $\alpha>1$ if and only if $\gamma>1.5$.

$$\frac{\partial^2 \psi_s(\alpha,\gamma)}{\partial \alpha^2} = \frac{1}{\gamma-1}\left[\frac{2\gamma-1}{\gamma-1}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}(\alpha+1)^{\frac{2-\gamma}{\gamma-1}} - \alpha^{\frac{2-\gamma}{\gamma-1}} - \frac{2-\gamma}{\gamma-1}\alpha^{\frac{3-2\gamma}{\gamma-1}}\right]$$

Multiply by $(\gamma-1)/\alpha^{\frac{2-\gamma}{\gamma-1}}$ and denote the expression by $\varphi_s(\alpha,\gamma)$.

$$\varphi_s(\alpha,\gamma) = \frac{2\gamma-1}{\gamma-1}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}\left(\frac{\alpha+1}{\alpha}\right)^{\frac{2-\gamma}{\gamma-1}} - \frac{2-\gamma}{\gamma-1}\alpha^{-1} - 1 \quad (34)$$

In what follows we will prove that $\varphi_s(\alpha,\gamma) > 0$ for any $\alpha > 1$ if and only if $\gamma > 1.5$. (Note that $\varphi_s(\alpha,1.5) = 0$ and $\varphi_s(\alpha,2) = \frac{1}{2}$.)

Substitute $\alpha = 1$ in equation (34).

$$\varphi_s(1,\gamma) = \frac{2\gamma-1}{2(\gamma-1)} - \frac{2-\gamma}{\gamma-1} - 1$$

It is straightforward to show that $\varphi_s(1,\gamma) > 0$ if and only if $\gamma > 1.5$. Furthermore, $\lim_{\alpha\to\infty}\varphi_s(\alpha,\gamma) = \frac{2\gamma-1}{\gamma-1}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}} - 1 > 0$ if and only if $\gamma > 1.5$ (proved in Supplementary Appendix 1.2).

Now differentiate $\varphi_s(\alpha,\gamma)$ with respect to α.

$$\frac{\partial \varphi_s(\alpha,\gamma)}{\partial \alpha} = \frac{2-\gamma}{(\gamma-1)\alpha^2}\left[1 - \frac{2\gamma-1}{\gamma-1}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}\left(\frac{\alpha+1}{\alpha}\right)^{\frac{3-2\gamma}{\gamma-1}}\right] \quad (35)$$

Denote the term in the square brackets by $\nu_s(\alpha,\gamma)$. Note that $\nu_s(1,\gamma) = 1 - \frac{2\gamma-1}{4(\gamma-1)} > 0$, $\lim_{\alpha\to\infty}\nu_s(\alpha,\gamma) = 1 - \frac{2\gamma-1}{\gamma-1}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}} < 0$ and $\partial\nu_s(\alpha,\gamma)/\partial\alpha = \frac{(2\gamma-1)(3\gamma-2)}{(\gamma-1)^2\alpha^2}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}\left(\frac{\alpha+1}{\alpha}\right)^{\frac{4-3\gamma}{\gamma-1}} < 0$ if and only if $\gamma > 1.5$. Therefore there exists a unique $\widetilde{\alpha} > 1$ for which $\nu_s(\widetilde{\alpha},\gamma) = 0$. This implies that $\partial\varphi_s(\alpha,\gamma)/\partial\alpha\,|_{\alpha=\widetilde{\alpha}} = 0$.

We have shown that $\varphi_s(1,\gamma) > 0$ and $\lim_{\alpha\to\infty}\varphi_s(\alpha,\gamma) > 0$ if and only if $\gamma > 1.5$. Therefore if also $\varphi_s(\widetilde{\alpha},\gamma) > 0$ if and only if $\gamma > 1.5$, the proof is complete.

By definition

$$\frac{2\gamma-1}{\gamma-1}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}\left(\frac{\widetilde{\alpha}+1}{\widetilde{\alpha}}\right)^{\frac{3-2\gamma}{\gamma-1}}=1 \tag{36}$$

Substitute $\widetilde{\alpha}$ in (34) and use (36).

$$\begin{aligned}
\varphi_s(\widetilde{\alpha},\gamma) &= \frac{2\gamma-1}{\gamma-1}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}\left(\frac{\widetilde{\alpha}+1}{\widetilde{\alpha}}\right)^{\frac{2-\gamma}{\gamma-1}}-\frac{2-\gamma}{\gamma-1}\widetilde{\alpha}^{-1}-1 \\
&= \left[\frac{2\gamma-1}{\gamma-1}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}\left(\frac{\widetilde{\alpha}+1}{\widetilde{\alpha}}\right)^{\frac{3-2\gamma}{\gamma-1}}\right]\left(\frac{\widetilde{\alpha}+1}{\widetilde{\alpha}}\right)-\frac{2-\gamma}{\gamma-1}\widetilde{\alpha}^{-1}-1 \\
&= \frac{\widetilde{\alpha}+1}{\widetilde{\alpha}}-\frac{2-\gamma}{\gamma-1}\widetilde{\alpha}^{-1}-1 \\
&= \frac{2\gamma-3}{\widetilde{\alpha}(\gamma-1)} > 0 \text{ if and only if } \gamma > 1.5
\end{aligned}$$

This proves that $\varphi_s(\alpha,\gamma) > 0$ for any $\alpha > 1$ if and only if $\gamma > 1.5$. Therefore $\partial^2\psi_s(\alpha,\gamma)/\partial\alpha^2 > 0$ for any $\alpha > 1$ if and only if $\gamma > 1.5$. Accordingly, joint ownership dominates common ownership if and only if $\gamma > 1.5$. Q.E.D.

Proof of Proposition 2.

(i) The aggregate gain from deviation under common ownership is equal to

$$\begin{aligned}
G^C &= \left[\theta_h\left(y^*+y_h^C\right)-c\left(y_h^C\right)\right]+\left[\theta_l\left(y^*+y_l^C\right)-c\left(y_l^C\right)\right]-\left[2\left(\theta_l+\theta_h\right)y^*-2c\left(y^*\right)\right] \\
&= \left[\theta_h y_h^C-c\left(y_h^C\right)\right]-\left[\theta_h y^*-c\left(y^*\right)\right]+\left[\theta_l y_l^C-c\left(y_l^C\right)\right]-\left[\theta_l y^*-c\left(y^*\right)\right] > 0.
\end{aligned}$$

$G^C > 0$ since y_h^C maximizes the first term in square brackets and y_l^C maximizes the third term.

In the same way we can derive the aggregate gain from deviation under joint ownership.

$$G^J = 2\left[\frac{1}{2}\left(\theta_l+\theta_h\right)y^J-c\left(y^J\right)\right]-2\left[\frac{1}{2}\left(\theta_l+\theta_h\right)y^*-c\left(y^*\right)\right] > 0 \tag{37}$$

Therefore the difference in the gains is equal to

$$G^C - G^J = \left[\theta_h y_h^C - c\left(y_h^C\right)\right] + \left[\theta_l y_l^C - c\left(y_l^C\right)\right] - 2\left[\frac{1}{2}\left(\theta_l + \theta_h\right) y^J - c\left(y^J\right)\right].$$

Equation (13) in Section 3 proves that $G^J < G^C$ for any $\theta_h > \theta_l$.

(ii) Proposition 1 shows that $S^{p,J} > S^{p,C}$ if and only if $\gamma > 1.5$ and therefore $L^J < L^C$ if and only if $\gamma > 1.5$. Q.E.D.

Proof of Proposition 3.

To derive the explicit form of $\underline{\delta}^J$ we first substitute (28) and (29) in (37) obtaining

$$\begin{aligned} G^J &= 2\left[\frac{1}{2}\left(\theta_l + \theta_h\right)\left(\frac{\theta_l + \theta_h}{2\gamma}\right)^{\frac{1}{\gamma-1}} - \left(\frac{\theta_l + \theta_h}{2\gamma}\right)^{\frac{\gamma}{\gamma-1}}\right] \\ &\quad -2\left[\frac{1}{2}\left(\theta_l + \theta_h\right)\left(\frac{\theta_l + \theta_h}{\gamma}\right)^{\frac{1}{\gamma-1}} - \left(\frac{\theta_l + \theta_h}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}\right] \\ &= \left(\frac{\theta_l + \theta_h}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}\left[\left(\gamma - 1\right)\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}} - \left(\gamma - 2\right)\right] > 0. \end{aligned} \tag{38}$$

(38) is positive by equation (37).

$G^J + L^J$ equals

$$\begin{aligned} G^J + L^J &= 2\left[\frac{1}{2}\left(\theta_l + \theta_h\right) y^J - c\left(y^J\right)\right] - 2\left[\frac{1}{2}\left(\theta_l + \theta_h\right) y^* - c\left(y^*\right)\right] \\ &\quad +2\left[\left(\theta_l + \theta_h\right) y^* - c\left(y^*\right)\right] - 2\left[\left(\theta_l + \theta_h\right) y^J - c\left(y^J\right)\right] \\ &= \left(\theta_l + \theta_h\right)\left(y^* - y^J\right) \\ &= \left(\theta_l + \theta_h\right)\left[\left(\frac{\theta_l + \theta_h}{\gamma}\right)^{\frac{1}{\gamma-1}} - \left(\frac{\theta_l + \theta_h}{2\gamma}\right)^{\frac{1}{\gamma-1}}\right] \\ &= \left(\frac{1}{\gamma}\right)^{\frac{1}{\gamma-1}}\left(\theta_l + \theta_h\right)^{\frac{\gamma}{\gamma-1}}\left[1 - \left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}\right]. \end{aligned} \tag{39}$$

Using equations (38) and (39) we obtain

$$\underline{\delta}^J = \frac{G^J}{G^J + L^J} = \frac{(\gamma - 1)\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}} - (\gamma - 2)}{\gamma\left[1 - \left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}\right]}. \tag{40}$$

Similarly, G^C and $G^C + L^C$ equal

$$\begin{aligned}
G^C &= \left[\theta_h\left(\frac{\theta_h}{\gamma}\right)^{\frac{1}{\gamma-1}} - \left(\frac{\theta_h}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}\right] + \left[\theta_l\left(\frac{\theta_l}{\gamma}\right)^{\frac{1}{\gamma-1}} - \left(\frac{\theta_l}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}\right] \\
&\quad - \left[(\theta_l + \theta_h)\left(\frac{\theta_l + \theta_h}{\gamma}\right)^{\frac{1}{\gamma-1}} - 2\left(\frac{\theta_l + \theta_h}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}\right] \\
&= (\gamma - 1)\left(\frac{\theta_h}{\gamma}\right)^{\frac{\gamma}{\gamma-1}} + (\gamma - 1)\left(\frac{\theta_l}{\gamma}\right)^{\frac{\gamma}{\gamma-1}} - (\gamma - 2)\left(\frac{\theta_l + \theta_h}{\gamma}\right)^{\frac{\gamma}{\gamma-1}} \\
&= \left(\frac{\theta_h}{\gamma}\right)^{\frac{\gamma}{\gamma-1}}\left[(\gamma - 1) + (\gamma - 1)\,\alpha^{\frac{\gamma}{\gamma-1}} - (\gamma - 2)(\alpha + 1)^{\frac{\gamma}{\gamma-1}}\right] \qquad (41)
\end{aligned}$$

$$\begin{aligned}
G^C + L^C &= \left[\theta_h y_h^C - c\left(y_h^C\right)\right] + \left[\theta_l y_l^C - c\left(y_l^C\right)\right] - \left[(\theta_l + \theta_h)\,y^* - 2c\,(y^*)\right] \\
&\quad + \left[(\theta_l + \theta_h)\,2y^* - 2c\,(y^*)\right] - \left[\theta_h\left(y_h^C + y_l^C\right) - c\left(y_h^C\right)\right] - \left[\theta_l\left(y_h^C + y_l^C\right) - c\left(y_l^C\right)\right] \\
&= \theta_h\left(y^* - y_l^C\right) + \theta_l\left(y^* - y_h^C\right) \\
&= \theta_h\left[\left(\frac{\theta_l + \theta_h}{\gamma}\right)^{\frac{1}{\gamma-1}} - \left(\frac{\theta_l}{\gamma}\right)^{\frac{1}{\gamma-1}}\right] + \theta_l\left[\left(\frac{\theta_l + \theta_h}{\gamma}\right)^{\frac{1}{\gamma-1}} - \left(\frac{\theta_h}{\gamma}\right)^{\frac{1}{\gamma-1}}\right] \\
&= (\theta_h)^{\frac{\gamma}{\gamma-1}}\left(\frac{1}{\gamma}\right)^{\frac{1}{\gamma-1}}\left[\left((\alpha + 1)^{\frac{1}{\gamma-1}} - \alpha^{\frac{1}{\gamma-1}}\right) + \alpha\left((\alpha + 1)^{\frac{1}{\gamma-1}} - 1\right)\right] \qquad (42)
\end{aligned}$$

We have substituted in $\theta_h = \alpha\theta_l$ where $\alpha > 1$. Using equations (41) and (42) we obtain

$$\underline{\delta}^C = \frac{(\gamma - 1) + (\gamma - 1)\,\alpha^{\frac{\gamma}{\gamma-1}} - (\gamma - 2)(\alpha + 1)^{\frac{\gamma}{\gamma-1}}}{\gamma\left[\left((\alpha + 1)^{\frac{1}{\gamma-1}} - \alpha^{\frac{1}{\gamma-1}}\right) + \alpha\left((\alpha + 1)^{\frac{1}{\gamma-1}} - 1\right)\right]}. \tag{43}$$

In Supplementary Appendix 2.1 we establish that

$$\underline{\delta}^J > \underline{\delta}^C \Leftrightarrow \chi_r(\alpha,\gamma) < \psi_r(\alpha,\gamma)$$

where

$$\chi_r(\alpha,\gamma) = (\gamma-1)\left[1-\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}\right] + \alpha\left[(\gamma-1)\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}} - (\gamma-2)\right],$$

$$\psi_r(\alpha,\gamma) = \left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}(\alpha+1)^{\frac{\gamma}{\gamma-1}} - (\gamma-1)\,\alpha^{\frac{\gamma}{\gamma-1}}\left[1-\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}\right]$$
$$-\alpha^{\frac{1}{\gamma-1}}\left[(\gamma-1)\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}} - (\gamma-2)\right].$$

Subscript r denotes repeated game. Differentiating with respect to α gives

$$\frac{\partial\chi_r(\alpha,\gamma)}{\partial\alpha} = \left[(\gamma-1)\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}} - (\gamma-2)\right] > 0 \tag{44}$$

$$\frac{\partial\psi_r(\alpha,\gamma)}{\partial\alpha} = \frac{\gamma}{\gamma-1}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}(\alpha+1)^{\frac{1}{\gamma-1}} - \gamma\alpha^{\frac{1}{\gamma-1}}\left[1-\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}\right]$$
$$-\frac{1}{\gamma-1}\alpha^{\frac{2-\gamma}{\gamma-1}}\left[(\gamma-1)\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}} - (\gamma-2)\right]$$

Note that (44) is positive by equation (38).

Note that $\chi_r(1,\gamma) = \psi_r(1,\gamma) = 1$ and $\frac{\partial\chi_r(\alpha,\gamma)}{\partial\alpha}|_{\alpha=1} = \frac{\partial\psi_r(\alpha,\gamma)}{\partial\alpha}|_{\alpha=1} = \left[(\gamma-1)\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}} + (2-\gamma)\right]$. Since $\chi_r(\alpha,\gamma)$ and $\psi_r(\alpha,\gamma)$ are tangent at $\alpha = 1$ and $\chi_r(\alpha,\gamma)$ is linear and increasing in α, $\psi_r(\alpha,\gamma) \geq \chi_r(\alpha,\gamma)$ if $\partial\psi_r^2(\alpha,\gamma)/\partial\alpha^2 > 0$. The rest of the proof establishes that $\partial^2\psi_r(\alpha,\gamma)/\partial\alpha^2 > 0$ for any $\alpha > 1$ if and only if $\gamma > 2$.

$$\frac{\partial^2\psi_r(\alpha,\gamma)}{\partial\alpha^2} = \frac{1}{\gamma-1}\left\{\frac{\gamma}{\gamma-1}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}(\alpha+1)^{\frac{2-\gamma}{\gamma-1}} - \gamma\alpha^{\frac{2-\gamma}{\gamma-1}}\left[1-\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}\right]\right.$$
$$\left. -\frac{2-\gamma}{\gamma-1}\alpha^{\frac{3-2\gamma}{\gamma-1}}\left[(\gamma-1)\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}} - (\gamma-2)\right]\right\}.$$

Multiply by $(\gamma-1)/\alpha^{\frac{2-\gamma}{\gamma-1}}$ and denote the expression by $\varphi_r(\alpha,\gamma)$.

$$\varphi_r(\alpha,\gamma) = \alpha^{-1}\left\{\frac{\alpha\gamma}{\gamma-1}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}\left(\frac{\alpha+1}{\alpha}\right)^{\frac{2-\gamma}{\gamma-1}} - \gamma\alpha\left[1-\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}\right]\right.$$
$$\left. -\frac{2-\gamma}{\gamma-1}\left[(\gamma-1)\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}} - (\gamma-2)\right]\right\} \quad (45)$$

In Supplementary Appendix 2.2 and 2.3 we prove that $\varphi_r(1,\gamma) > 0$ and $\lim_{\alpha\to\infty}\varphi_r(\alpha,\gamma) = \gamma\left[\frac{\gamma}{\gamma-1}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}} - 1\right] > 0$ if and only if $\gamma > 2$.

Differentiate $\varphi_r(\alpha,\gamma)$ with respect to α.

$$\frac{\partial\varphi_r(\alpha,\gamma)}{\partial\alpha} = \frac{2-\gamma}{\gamma-1}\alpha^{-2}\left[-\frac{\gamma}{\gamma-1}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}\left(\frac{\alpha+1}{\alpha}\right)^{\frac{3-2\gamma}{\gamma-1}} + (\gamma-1)\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}} - (\gamma-2)\right] \quad (46)$$

Denote the term in the square brackets by $\nu_r(\alpha,\gamma)$. Since $-\frac{\gamma}{\gamma-1}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}}\left(\frac{\alpha+1}{\alpha}\right)^{\frac{3-2\gamma}{\gamma-1}} < 0$ and $(\gamma-1)\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}} - (\gamma-2) > 0$, for a given γ there exists a unique $\widehat{\alpha}$ (not necessarily greater than 1) for which $\nu_r(\widehat{\alpha},\gamma) = 0$.[30] Furthermore,

$$\nu_r(1,\gamma) = -\frac{\gamma}{4(\gamma-1)} + (\gamma-1)\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}} - (\gamma-2) > 0 \text{ if and only if } \gamma > 2 \quad (47)$$

[30] Note that $\widehat{\alpha}$ is not defined for $\gamma = 1.5$.

This is proved in Supplementary Appendix 2.2. (Note that equation (47) is equivalent to equation (A.2) in the Supplementary Appendix.) Differentiate $\nu_r(\alpha,\gamma)$ with respect to α.

$$\frac{\partial \nu_r(\alpha,\gamma)}{\partial \alpha} = \frac{\gamma(3-2\gamma)}{\alpha^2(\gamma-1)^2}\left(\frac{\alpha+1}{\alpha}\right)^{\frac{4-3\gamma}{\gamma-1}}\left(\frac{1}{2}\right)^{\frac{1}{\gamma-1}} > 0 \text{ if and only if } \gamma < 1.5 \tag{48}$$

Equations (47) and (48) determine the sign of $\nu_r(\alpha,\gamma)$ as in the first column of Table 1.

	$\nu_r(\alpha,\gamma)$	$\frac{\partial\varphi_r(\alpha,\gamma)}{\partial\alpha}$	$\varphi_r(\alpha,\gamma)$
$\gamma < 1.5$	$+$ if and only if $\alpha > \widehat{\alpha}$	$+$ if and only if $\alpha > \widehat{\alpha}$	$-$
$1.5 < \gamma < 2$	$-$	$-$	$-$
$\gamma > 2$	$-$ if and only if $\alpha > \widehat{\alpha}$	$+$ if and only if $\alpha > \widehat{\alpha}$	$+$

Table 1

The sign of $\frac{\partial\varphi_r(\alpha,\gamma)}{\partial\alpha}$ depends on the sign of $\nu_r(\alpha,\gamma)$ as per equation (46) and it is given in the second column of Table 1. Taking into account that $\varphi_r(1,\gamma) < 0$ and $\lim_{\alpha\to\infty}\varphi_r(\alpha,\gamma) < 0$ if and only if $\gamma < 2$ we can determine that $\varphi_r(\alpha,\gamma) < 0$ for $\gamma < 2$. In Supplementary Appendix 2.4 we prove that $\varphi_r(\alpha,\gamma) > 0$ if $\gamma > 2$.

This proves that $\varphi_r(\alpha,\gamma) > 0$ for any $\alpha > 1$ if and only if $\gamma > 2$. Therefore $\partial^2\psi_r(\alpha,\gamma)/\partial\alpha^2 > 0$ for any $\alpha > 1$ if and only if $\gamma > 2$. Accordingly, $\underline{\delta}^C < \underline{\delta}^J$ if and only if $\gamma > 2$. Q.E.D.

Proof of Proposition 4.

(i) The gain from deviation under ownership by agent i is equal to

$$\begin{aligned} G^i &= \frac{1}{2}(\theta_l+\theta_h)\left(y_i^i+y^*\right)+\frac{1}{2}(\theta_i-\theta_j)\left(y_i^i+\mu y^*\right)-c\left(y_i^i\right)+\frac{1}{2}(\theta_l+\theta_h)\left(y^*+y_j^i\right) \\ &\quad +\frac{1}{2}(\theta_j-\theta_i)\left(y^*+\mu y_j^i\right)-c\left(y_j^i\right)-2(\theta_l+\theta_h)y^*+2c(y^*) \\ &= \left[\theta_i y_i^i-c\left(y_i^i\right)\right]-\left[\theta_i y^*-c(y^*)\right] \\ &\quad +\left[\frac{1}{2}(\theta_l+\theta_h)y_j^i+\frac{1}{2}(\theta_j-\theta_i)\mu y_j^i-c\left(y_j^i\right)\right] \\ &\quad -\left[\frac{1}{2}(\theta_l+\theta_h)y^*+\frac{1}{2}(\theta_j-\theta_i)\mu y^*-c(y^*)\right] \end{aligned} \tag{49}$$

Using the envelope theorem and taking into account that $\partial y^*/\partial\mu=0$, we obtain

$$\frac{\partial G^h}{\partial\mu}=\frac{1}{2}(\theta_l-\theta_h)\left(y_l^h-y^*\right)>0 \tag{50}$$

$$\frac{\partial G^l}{\partial\mu}=\frac{1}{2}(\theta_h-\theta_l)\left(y_h^l-y^*\right)<0. \tag{51}$$

Since $G^h=G^l=G^C$ for $\mu=1$, equations (50) and (51) prove that $G^h<G^C<G^l$ for any $\mu<1$. According to Proposition 2 $G^J<G^C$. Therefore $max\left\{G^J,G^h\right\}<G^C<G^l$.

$(ii)-(iii)$ Equations (18) and (19) prove that $L^h<L^C<L^l$. Proposition 1 proves that $L^C<L^J$ if and only if $\gamma<1.5$ proving the statements in the Proposition. Q.E.D.

Proof of Proposition 5.

(i) According to Proposition 3 $\underline{\delta}^J<\underline{\delta}^C$ if and only if $\gamma<2$. According to equations (14) – (17) $\underline{\delta}^C=\underline{\delta}^h=\underline{\delta}^l$ if $\mu=1$. Therefore for $\mu=1$ $\underline{\delta}^J<\min\left(\underline{\delta}^C,\underline{\delta}^h,\underline{\delta}^l\right)$ if $\gamma<2$. By continuity the same holds for $\mu\to1$.

(ii) In Supplementary Appendix 3.5 we prove that for $\mu=0$ $\underline{\delta}^h<\underline{\delta}^J<\underline{\delta}^l$ if and only if $\gamma<2$. According to Proposition 3 $\underline{\delta}^J<\underline{\delta}^C$ if and only if $\gamma<2$. Therefore for $\mu = 0$ $\underline{\delta}^h < \min\left(\underline{\delta}^C, \underline{\delta}^J, \underline{\delta}^l\right)$ if and only if $\gamma < 2$. By continuity the same holds for $\mu \to 0$.

(iii) According to Proposition 3 $\underline{\delta}^C < \underline{\delta}^J$ if and only if $\gamma > 2$. In Supplementary Appendix 3.6 we prove that $\underline{\delta}^C \leq \min\left(\underline{\delta}^h, \underline{\delta}^l\right)$ if $\gamma > 2$ and $\frac{\theta_l}{\theta_h} \to 0$. Therefore $\underline{\delta}^C \leq \min\left(\underline{\delta}^J, \underline{\delta}^h, \underline{\delta}^l\right)$ if $\gamma > 2$ and $\frac{\theta_l}{\theta_h} \to 0$.

(iv) In Supplementary Appendix 3.5 we prove that for $\mu = 0$ $\underline{\delta}^l < \underline{\delta}^J < \underline{\delta}^h$ if and only if $\gamma > 2$. According to Proposition 3 $\underline{\delta}^C < \underline{\delta}^J$ if and only if $\gamma > 2$. In Supplementary Appendix 3.7 we prove that $\underline{\delta}^l < \underline{\delta}^C$ if $\gamma > 2$, $\frac{\theta_l}{\theta_h} \to 1$ and $\mu \to 0$. Therefore $\underline{\delta}^l < \min\left(\underline{\delta}^J, \underline{\delta}^C, \underline{\delta}^h\right)$ if $\gamma > 2$, $\frac{\theta_l}{\theta_h} \to 1$ and $\mu \to 0$. Q.E.D.

A.2 Lower punishment investments

Denote the punishment investment by y_i^p. If the agents are willing to engage in punishing by lower investments than the optimal investments of the static game $\left(y_i^p < y_i^\omega\right)$, first-best investments can be sustained for lower discount factors than in Section 6. The maximum transfers are now

$$F^{h,\omega} + F^{l,\omega} = \frac{S^* - P_h^\omega\left(y_h^\omega, y_l^p\right) - P_l^\omega\left(y_l^\omega, y_h^p\right)}{(1-\delta)} \tag{52}$$

where $P_j^\omega\left(y_j^\omega, y_i^p\right)$ is agent j's payoff when he chooses y_j^ω and agent i chooses punishment investment y_i^p. y_i^p has to be incentive compatible as determined by

$$P_i^\omega\left(y_i^p, y_j^\omega\right) + \delta\left[F^{j,\omega} + \frac{1}{1-\delta}P_i^*\left(y^*, y^*\right)\right] \geq P_i^\omega\left(y_i^\omega, y_j^\omega\right) + \delta\left[-F^{i,\omega} + \frac{1}{1-\delta}P_i^*\left(y^*, y^*\right)\right] \tag{53}$$

where $P_i^*(y^*, y^*)$ is agent i's payoff under cooperation. Equation (53) simplifies to

$$\delta\left(F^{h,\omega} + F^{l,\omega}\right) \geq P_i^{\omega}\left(y_i^{\omega}, y_j^{\omega}\right) - P_i^{\omega}\left(y_i^{p}, y_j^{\omega}\right). \tag{54}$$

Equation (54) clearly holds for $y_i^p = y_i^{\omega}$. Now consider lower y_i^p. The gain from deviating from y_i^p increases for lower y_i^p since $\partial P_i^{\omega}\left(y_i^p, y_j^{\omega}\right)/\partial y_i^p > 0$ for $y_i^p \in [0, y_i^{\omega})$. However, also the left-hand-side of (54) increases since harsher punishment investment increases the maximum transfers, $\partial F^{j,\omega}/\partial y_i^p < 0$. Under joint ownership the effect of lower y_i^p is determined by

$$\delta\frac{\partial\left(F^{h,J} + F^{l,J}\right)}{\partial y_i^p} + \frac{\partial P_i^J\left(y_i^p, y^J\right)}{\partial y_i^p} = -\frac{\delta\frac{1}{2}(\theta_l + \theta_h)}{(1-\delta)} + \frac{1}{2}(\theta_l + \theta_h) - c'\left(y_i^p\right)$$

$$= \frac{1}{(1-\delta)}\left[(1-2\delta)\frac{1}{2}(\theta_l + \theta_h) - (1-\delta)\,c'\left(y_i^p\right)\right] \tag{55}$$

For any $\delta \geq 1/2$ the transfer effect dominates and (55) is negative. Therefore all $y_i^p \in \left[0, y^J\right]$ are incentive compatible. Similarly, we can verify that for any $\delta \geq 1/2$ all $y_i^p \in \left[0, y_i^C\right]$ are incentive compatible under common ownership.

The incentive compatibility constraint for y^* is still given by (26) with the exception that $\left(F^{h,\omega} + F^{l,\omega}\right)$ is given by (52). Since lower y_i^p relaxes this incentive compatibility constraint, we set y_i^p to its minimum value. Substituting $y_i^p = 0$ in the critical discount factor for y^* (equation (27)) we obtain

$$\delta \geq \frac{P_h^{d,\omega} + P_l^{d,\omega} - S^*}{P_h^{d,\omega} + P_l^{d,\omega} - P_h^{\omega}\left(y_h^{\omega}, 0\right) - P_l^{\omega}\left(y_l^{\omega}, 0\right)} = \frac{G^{\omega}}{(\theta_l + \theta_h)\,y^*}. \tag{56}$$

By Proposition 2 $G^J < G^C$. Therefore joint ownership dominates common ownership if $\delta \geq 1/2$. It can be shown that the same result holds also for $\delta < 1/2$.

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