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Wolfgang Buchholz, Keisuke Hattori

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A Paradox of Coalition Building in Public Good Provision

Abstract

This paper considers endogenous coalition formations and endogenous technology choices in a model of private provision of global public goods. We show that the possibility of future interstate (partial) coordination may hinder the current adoption of better technology by a country outside the cooperation, which may exacerbate an existing underprovision problem. In particular, in the subgame perfect equilibrium of a three-stage game, we find two paradoxical results: prohibition of the formation of future partial coalitions encourages the country outside the cooperation to adopt better technology, which could lead to an increase in the total public good supply and an improvement of global welfare. The results have an important policy implication: in the context of the Paris Agreement, for example, a large country announces lower nationally determined contributions by a strategic incentive to adopt lower technology to motivate coalition building by other nations, which in the end may lead to lower aggregate public-good supply and global welfare.

JEL-Codes: H410, F530, Q540, Q550.

Keywords: coalition formation, public goods, endogenous technology, environmental agreements.

Wolfgang Buchholz
Department of Economics
University of Regensburg / Germany
wolfgang.buchholz@ur.de

Keisuke Hattori
School of Business
Aoyama Gakuin University / Japan
hattori@busi.aoyama.ac.jp

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1 Introduction

If public goods are privately provided by independently acting agents, their supply will normally remain below Pareto optimal levels (e.g., Cornes and Sandler 1996). If the cooperative action of all agents involved, leading to a first-best Pareto efficient outcome in a "grand coalition", is not possible, partial cooperation by a subgroup of agents seems to be a promising approach to increase the public good supply and thus to at least mitigate the underprovision problem of public goods. In global climate policy, this is the hope that underlies the Paris Agreement of 2015: A group of willing countries proceeds, motivating other countries to follow suit so that supply of the global public good "climate" protection increases and, in the end, approximates its optimal level and makes all countries better off. However, as has been shown in several papers (e.g., Chiu 1997, and Buchholz et al. 1998), building a coalition may – due to crowding-out behavior by outsiders – not only be unprofitable for the coalition members but also building some coalitions may undermine the readiness of an even larger group of countries to form a coalition among themselves.

In this paper, we will present another potential drawback of coalition building that stems particularly from negative incentives for the choice of a contribution technology, i.e., the technology for greenhouse gas abatement in the case of climate change. Therefore, we will show in the standard framework of public good theory, which is used to explore the provision of global public goods in general and the strategic incentives that arise in international climate policy in particular (e.g., Buchholz and Sandler 2021, for an overview), that the expectation of the overall advantageous effects of coalition building is not necessarily correct if the production technology for the public good is endogenous. Then, coalition building by a group of agents, or "countries" in our specific context, may eliminate the incentive to develop and adopt a more productive contribution technology by another country, which in the end may lead to a lower public good supply and to less aggregate welfare, casting some shadows on the bottom-up approach.

The paper is organized as follows: Section 2 reviews the related literature. In Section 3, we present the basic structure of the model, which is a three-stage game. At stage 1, a country outside a group of countries chooses its technology for its public good contribution; at stage 2, a group of countries decides whether it should build a coalition and thus cooperatively determine its public good contribution; and finally at stage 3, the countries play a Nash game of voluntary public good supply given the decisions of the two previous stages. By backward induction, Section

4 characterizes the four cases of the Nash equilibrium of public good provision at the last stage, depending on the technology adoption at the first stage and coalition formation at the second stage. Section 5 considers the endogenous formation of a coalition by a group of countries at stage 2. Section 6 considers the technology choice by a leading country outside the group at stage 1. In Section 7, we provide the two main outcomes of the "coalition paradox." Finally, Section 8 concludes the paper.

2 Related Literature

In the literature on the private provision of public goods, many studies have shown that making (prior) unilateral commitments by an agent that lead others to expect that the agent can or will provide more public goods, such as obtaining a better technology for providing public goods or becoming more interested in the public good, will encourage others to free ride on this agent's contributions, which not only worsens the utility of the agent but can also lead to a reduction in the total public good supply (see Hoel 1991, Buchholz and Konrad 1994, Ihori 1996, and Hattori 2005, among many others). Our current study is in line with these "technology and preference paradoxes". However, it depicts a more complicated situation in which an agent outside of a possible future coalition is hesitant to adopt a better technology for public good provision, not only because she fears that the adoption will reduce the future contribution of the other agents but also because it might prevent future coalition formation. As a consequence, eliminating the possibility of future partial coalition formation will encourage the outside agent to adopt better technologies, which may in the end lead to a greater total public good supply and higher aggregate welfare.

Our study also relates to studies on the profitability of partial cooperation and coalition building for potential coalition members and the total public good supply in the private provision of public goods (see Chiu 1997, Barrett 1994, Buchholz et al. 1998, Buchholz et al. 2014, and Hattori 2015, among many others). In this context, Chiu (1997) shows that members in the partial coalition only benefit from cooperation if the size of the coalition exceeds a critical mass, whose size increases with the degree of externality and decreases with the elasticity of substitution of the outsiders' utility functions (see also Buchholz et al. 1998). Reminiscent of the studies on "(horizontal) merger profitability" by Salant et al. (1986) and others in the field of industrial organization, the outsiders will gain through free riding on the coalition's contributions and attain a greater benefit than the coalition members. This is also the reason why many international environmental agreements (IEAs) are unlikely to be internally stable (see, e.g., Finus 2001, Barrett 2005 and Finus et al. 2006). While our study does not consider coalition stability, i.e., the participation/withdrawal decision of countries to join/leave a coalition, it analyzes the linkage between the endogenous coalition formation decision by an exogenously given group of pioneering benevolent countries (i.e., the profitability issue), on the one hand, and the strategic incentives for agents outside the coalition to adopt better technologies for public good provision, on the other.

Sequential games of coalition formation or, equivalently, dissolution have also been considered by Buchholz and Eichenseer (2017) and Foucart and Wan (2018), respectively. These papers not only identify conditions (such as group size or preference intensity for the public good) under which a group of agents is willing to act cooperatively (or starting from an existing coalition or federation to decentralize the contribution decisions) but also examine the incentives for one group to act cooperatively if another group has already formed a coalition. Based on this subgame-perfect Nash equilibria of a coalition formation game are then determined, which will also be studied in our paper. The difference, however, is that we examine the coalition building decisions of a group of countries by which it reacts to a technology choice of an outsider country (and not to the coalition building of another group).

3 The Model

There are one leading country M and a group K, which consists of k small countries. As assumed in Hattori (2015), all countries are assumed to have symmetric Cobb-Douglas utility functions

$$u_i = u(c_i, G) = c_i \cdot G$$

and the budget constraint $c_i + g_i = w_i$, where c_i is private consumption of country i ($i \in \{M, K_1, K_2, \cdots, K_k\}$), g_i is its contribution to the public good, and w_i is its exogenously given income that is measured in units of the private good. The public good supply is denoted by G. In Appendix A2, we consider the case of quasi-linear utility.

The public good is produced by a summation technology for which the marginal rate of transformation between the private and the public good, i.e., the countries' productivity in providing

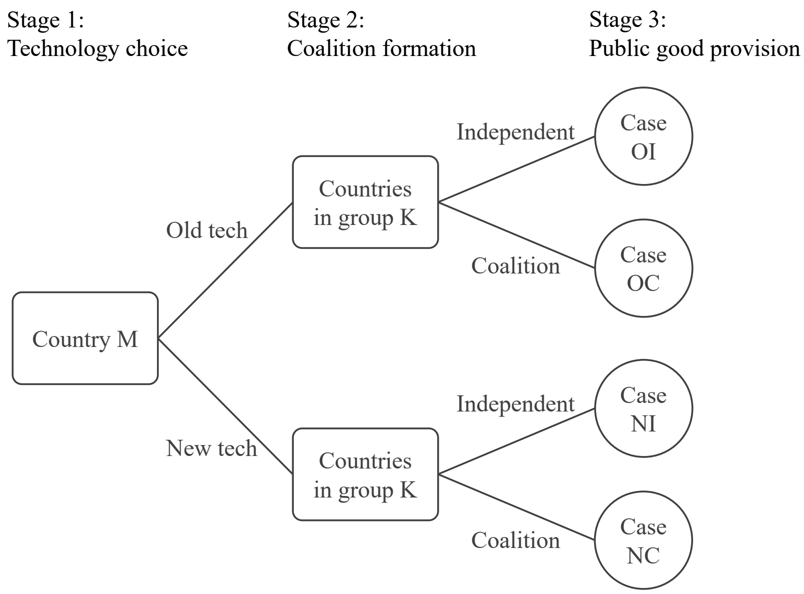

Figure 1: The structure of the sequential game

the public good, may differ between countries in group K and country M.

We consider a three-stage game: at stage 1, country M decides whether it should apply a good (new) contribution technology with productivity $1 + a$ (Strategy N), where $a > 0$ or apply an old (status-quo) technology with productivity 1 (Strategy O); at stage 2, the countries in group K decide whether they should form a cooperatively acting coalition (Strategy C) or act independently (Strategy I); at stage 3, the Nash equilibrium of public provision emerges given the technology choice of country M and the coalition formation decision by group K. Therefore, the total amount of public goods is given by $G = \sum_{i=1}^{k} g_{Ki} + (1 + a)g_M$ when country M adopts a new technology and $G = \sum_{i=1}^{k} g_{Ki} + g_M$ when country M adopts the old technology.

The structure of this sequential game is visualized by a game tree in Figure 1.

For the determination of the subgame-perfect Nash equilibria (SPNE) by backward induction, we make the following assumptions.

Assumption 1. $w_K \leq w_M < 2w_K$

Assumption 2. $k \geq 4$

Assumption 1 implies that the income of country M is larger than or equal to that of the countries in group K, but at most less than twice as large. The assumption guarantees the interior solution in the benchmark case in which country M does not adopt the new technology and group K does not form a coalition. We define

$$b \equiv \frac{w_M}{w_K} \in [1, 2),$$

representing the income size of country M relative to the income of group K countries. Assumption 2 implies that group K consists of at least four countries, which ensures that country M will be a free rider in stage 3 when group K forms a coalition. The assumption is for simplicity and is relaxed in Appendix A1.

4 The Nash Equilibrium of Public Good Provision at Stage 3

At stage 3, each country chooses its contribution to the public good. Depending on country M's technology choices at stage 1 and group K's coalition formation choices, there are four cases to be considered.

4.1 Case OI: M chooses old tech O, and countries in K choose independent I

Here, we derive the Nash equilibrium at stage 3 in the benchmark case in which country M chooses the old technology and group K chooses to act independently (hereafter denoted as "Case OI").

Since group K does not form a coalition, $k+1$ countries (country M choosing the old technology and countries Ki) noncooperatively and simultaneously choose their contributions. From the first-order conditions of the utility maximization problem, we have the following reaction functions:

$$g_M\left(g_{Ki}\right) = \frac{w_M - \sum_{i=1}^{k} g_{Ki}}{2} \qquad \text{for country } M,$$
$$g_{Ki}\left(g_M, g_{Kj}\right) = \frac{w_K - g_M - \sum_{j \neq i}^{k} g_{Kj}}{2} \qquad \text{for country } Ki.$$

Then, the Nash equilibrium is obtained as

$$g_{Ki}^{OI} = \frac{2w_K - w_M}{k+2}, \quad g_M^{OI} = \frac{(k+1)w_M - kw_K}{k+2}, \quad G^{OI} = \frac{kw_K + w_M}{k+2},$$
$$u_{Ki}^{OI} = u_M^{OI} = \left(\frac{kw_K + w_M}{k+2}\right)^2, \quad TU^{OI} = ku_{Ki}^{OI} + u_M^{OI},$$

where the superscript OI denotes the equilibrium value of Case OI. In the above expressions, TU^{OI} represents the sum of all countries' utility, i.e., the aggregate world welfare. From Assumption 1, we necessarily have interior solutions for $g_{Ki}^{OI} \geq 0$ and $g_M^{OI} \geq 0$.

4.2 Case NI: M chooses new tech N, and countries in K choose independent I

Here, we consider a case in which country M adopts the new technology and group K chooses to act independently (hereafter we call "Case NI").

In this case, country M's technology parameter is $(1+a)$, not unity. We have the following interior solutions:

$$g_{Ki}^{NI} = \frac{2w_K - (1+a)w_M}{k+2}, \quad g_M^{NI} = \frac{(k+1)(1+a)w_M - kw_K}{(1+a)(k+2)}, \quad G^{NI} = \frac{kw_K + (1+a)w_M}{k+2},$$
$$u_{Ki}^{NI} = \left(\frac{kw_K + (1+a)w_M}{k+2}\right)^2, \quad u_M^{NI} = \frac{1}{1+a}\left(\frac{kw_K + (1+a)w_M}{k+2}\right)^2, \quad TU^{NI} = ku_{Ki}^{NI} + u_M^{NI}.$$

We can see from g_{Ki}^{NI} that when

$$a > a_1 \equiv \frac{2w_K - w_M}{w_M} = \frac{2-b}{b}, \tag{1}$$

each country Ki becomes a free rider (i.e., $g_{Ki}^{NI} = 0$). In this corner-solution case, the equilibrium is characterized by

$$g_{Ki}^{NI}|_{g_{Ki}=0} = 0, \quad g_M^{NI}|_{g_{Ki}=0} = \frac{w_M}{2}, \quad G^{NI}|_{g_{Ki}=0} = \frac{(1+a)w_M}{2},$$
$$u_{Ki}^{NI}|_{g_{Ki}=0} = \frac{(1+a)w_K w_M}{2}, \quad u_M^{NI}|_{g_{Ki}=0} = (1+a)\left(\frac{w_M}{2}\right)^2,$$
$$TU^{NI}|_{g_{Ki}=0} = ku_{Ki}^{NI}|_{g_{Ki}=0} + u_M^{NI}|_{g_{Ki}=0}.$$

4.3 Case OC: M chooses old tech O, and K chooses cooperation C

The next case is the one in which country M chooses the old technology and group K forms a coalition. In this case, group K makes a collective decision about the contribution to the public goods to maximize the utility of the member countries. Group K's maximization problem at stage 3 is $\max_{g_K}(w_K - g_K)(kg_K + g_M)$, given country M's contribution, g_M.

Assuming an interior solution, the Nash equilibrium is characterized by $g_{Ki}^{OC} = \frac{2kw_K - w_M}{3k}$ and

$g_M^{OC} = \frac{2w_M - kw_K}{3}$. However, from Assumptions 1 and 2, we have $g_M^{OC} < 0$ (because $2w_M - kw_K = (2b-k)w_K < 0$), implying country M necessarily becomes a free rider in Case OC. Thus, the equilibrium is characterized by

$$g_{Ki}^{OC}|_{g_M=0} = \frac{w_K}{2}, \quad g_M^{OC}|_{g_M=0} = 0, \quad G^{OC}|_{g_M=0} = \frac{kw_K}{2},$$
$$u_{Ki}^{OC}|_{g_M=0} = k\left(\frac{w_K}{2}\right)^2, \quad u_M^{OC}|_{g_M=0} = k\frac{w_K w_M}{2},$$
$$TU^{OC}|_{g_M=0} = ku_{Ki}^{OC}|_{g_M=0} + u_M^{OC}|_{g_M=0}.$$

4.4 Case NC: M chooses new tech N, and K chooses cooperation C

The last case is the one in which country M adopts the new technology and group K forms a coalition. In this case, we have two possible equilibria with interior and corner solutions, depending on the degree of technology improvement, as reflected by a. First, we have the following Nash equilibrium with interior solutions:

$$g_{Ki}^{NC} = \frac{2kw_K - (1+a)w_M}{3k}, \quad g_M^{NC} = \frac{2(1+a)w_M - kw_K}{3(1+a)}, \quad G^{NC} = \frac{kw_K + (1+a)w_M}{3},$$
$$u_{Ki}^{NC} = \frac{1}{k}\left(\frac{kw_K + (1+a)w_M}{3}\right)^2, \quad u_M^{NC} = \frac{1}{1+a}\left(\frac{kw_K + (1+a)w_M}{3}\right)^2, \quad TU^{NC} = ku_{Ki}^{NC} + u_M^{NC}.$$

Second, when $2(1+a)w_M - kw_K < 0$, or equivalently

$$a < a_2 \equiv \frac{k-2b}{2b}, \tag{2}$$

country M becomes a free rider ($g_M^{NC} = 0$). In this case, the equilibrium is characterized as $g_{Ki}^{NC}|_{g_M=0}$, $g_M^{NC}|_{g_M=0}$, $G^{NC}|_{g_M=0}$, $u_{Ki}^{NC}|_{g_M=0}$, and $u_M^{NC}|_{g_M=0}$, which are exactly the same those in Case OC.

Third, when $2kw_K - (1+a)w_M < 0$, or equivalently

$$a > a_3 \equiv \frac{2k-b}{b}, \tag{3}$$

group K chooses to be a free rider. In this case, the equilibrium is characterized as $g_{Ki}^{NC}|_{g_{Ki}=0}$, $g_M^{NC}|_{g_{Ki}=0}$, $G^{NC}|_{g_{Ki}=0}$, $u_{Ki}^{NC}|_{g_{Ki}=0}$, and $u_M^{NC}|_{g_{Ki}=0}$, which are the same, respectively, as $g_{Ki}^{NI}|_{g_{Ki}=0}$, $g_M^{NI}|_{g_{Ki}=0}$, $G^{NI}|_{g_{Ki}=0}$, $u_{Ki}^{NI}|_{g_{Ki}=0}$, and $u_M^{NI}|_{g_{Ki}=0}$ in Case NI.

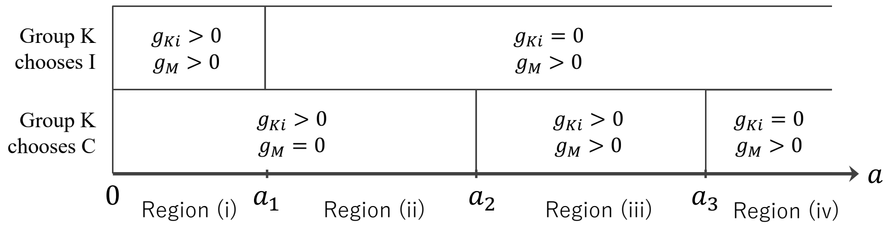

Figure 2: The four regions for various improved technology levels

5 Coalition formation decision of group K

This section investigates the second-stage coalition formation decision by group K at stage 2 given the technology choice by country M at stage 1.

First, we investigate group K's incentive to form a coalition when country M does not adopt a new technology and has chosen O. Comparing u_{Ki}^{OI} with $u_{Ki}^{OC}|_{g_M=0}$, we have

$$u_{Ki}^{OI} - u_{Ki}^{OC}|_{g_M=0} = -\frac{kw_K^2(k^2-8b) + 4w_K^2(k-b^2)}{4(2+k)^2} < 0.$$

Thus, we obtain the following lemma:

Lemma 1. *If country M chooses O at the first stage, then group K always chooses C at the second stage, which makes country M a free rider.*

Second, we investigate group K's incentive to form a coalition when country M adopts a new technology and has chosen N. Before doing that, we confirm from (1), (2), and (3) that $a_1 \leq a_2 < a_3$ holds because $a_2 - a_1 = (k-4)/(2b) \geq 0$ and $a_3 - a_2 = (k+b)/b > 0$. Hence, we can distinguish four regions, (i), (ii), (iii), and (iv), for the productivity parameter a, which is presented in Figure 2.

(i) When $0 \leq a < a_1$, comparing u_{Ki}^{NI} with $u_{Ki}^{NC}|_{g_M=0}$, we have

$$u_{Ki}^{NI} - u_{Ki}^{NC}|_{g_M=0} = -\frac{w_K^2}{4(2+k)^2}\left[4(\underbrace{k-(1+a)^2b^2}_{>0 \text{ from } a<a_1}) + k(\underbrace{k^2-8(1+a)b}_{>0 \text{ from } a<a_1})\right] < 0. \quad (4)$$

Thus, we have $u_{Ki}^{NI} < u_{Ki}^{NC}|_{g_M=0}$ implying that group K forms a coalition.

(ii) When $a_1 \leq a < a_2$, each country Ki would be a free rider in Case NI and country M would be a free rider in Case NC. Then we have

$$u_{Ki}^{NI}|_{g_{Ki}=0} - u_{Ki}^{NC}|_{g_M=0} = -\frac{w_K^2}{4}\big[\underbrace{k - 2(1+a)b}_{>0 \text{ from } a<a_2}\big] < 0,$$

implying that group K forms a coalition.

(iii) When $a_2 \leq a < a_3$, each country Ki would be a free rider in Case NI, and both countries Ki and M would be a positive contributor in Case NC. Then we have

$$u_{Ki}^{NI}|_{g_{Ki}=0} - u_{Ki}^{NC} = \frac{w_K^2}{18k}\big[\underbrace{2(1+a)b - k}_{\geq 0 \text{ from } a>a_2}\big]\big[\underbrace{2k - (1+a)b}_{>0 \text{ from } a<a_3}\big] \geq 0$$

which indicates that group K chooses to be independent.

(iv) When $a \geq a_3$, each country Ki would be a free rider in both Cases NI and NC. Thus, group K is indifferent between forming a coalition and being independent. The presence of any small cost for coalition formation prevents them from forming a coalition.

In sum, when the technology improvement is large enough ($a \geq a_2$), adoption of new technology by country M hinders group K from forming a coalition.

Lemma 2. *If country M chooses N at the first stage, then group K chooses C for $a < a_2$ and I if $a \geq a_2$.*

6 Technology adoption decision of country M

Here, we investigate country M's technology choice at stage 1. We already know, from Lemma 1, that if country M chooses the old technology, then group K will form a coalition and M will enjoy a free-riding utility $u_M^{OC}|_{g_M=0}$. In addition, from lemma 2, we know that if country M chooses the new technology, then (a) group K will form a coalition and M will be able to free ride getting $u_M^{NC}|_{g_M=0}$ when $a < a_2$ and (b) group K will not form a coalition and M will be a positive contributor, getting $u_M^{NI}|_{g_{Ki}=0}$ for $a \geq a_2$. Then we have

(a) When $a < a_2$, we have $u_M^{OC}|_{g_M=0} - u_M^{NC}|_{g_M=0} = 0$.

(b) When $a \geq a_2$, we have

$$u_M^{OC}|_{g_M=0} - u_M^{NI}|_{g_{Ki}=0} = \frac{bw_K^2}{4}\left[2k - (1+a)b\right] \gtreqless 0 \;\Leftrightarrow\; a \lesseqgtr a_3.$$

Assertion (a) indicates that country M is indifferent between adopting old and new technologies: Group K's coalition building makes country M a free rider, irrespective of its technology adoption. Small costs for technology adoption make country M strictly refuse to adopt new technology. Assertion (b), which is central for our argument, shows that country M wants to stick to the old technology when $a \leq a_3$ because adopting a new technology would prevent group K from forming a coalition and thus allow country M to free ride. If technology improvement is extremely large enough $a > a_3$, then country M would adopt a new technology. Now, we assume $a < a_3$ because the threshold level a_3 becomes rather large: for the example of $w_K = 10$, $w_M = 15$, and $k = 5$, we have $a_3 = 17/3 \approx 6$. Now we have the following proposition.

Proposition 1. *Suppose $a < a_3$. In the subgame-perfect Nash equilibrium (SPNE) of the game, country M never has an incentive to adopt a new technology. In particular, country M is indifferent between adopting the old and the new technologies when $a \leq a_2$ and strictly prefers choosing the old technology when $a > a_2$.*

In the literature on the private provision of public goods, there is a well-known result that having a better technology for public good provision induces other agents to contribute less and, therefore, may worsen for itself (e.g., Buchholz and Konrad, 1994; Ihori, 1996; and Hattori, 2005). Our Proposition 1 states that having a better technology for public good provision may not be beneficial for itself not because it induces other countries to contribute less but because it may also prevent other countries from forming a coalition. This implies, as shown in the next section, that a country is more likely to stick to the old technology when faced with the possibility of future coalition formation of other countries.

7 Two paradoxes on coalition building

We now compare the total public good supply and the aggregate world welfare in the SPNE of the endogenous coalition formation game with those in the counterfactual situation where group K does not have the option of coalition formation (i.e., building a coalition is prohibited, e.g., through high transaction costs or political conflicts between the countries in group K, which make it impossible for them to achieve functioning cooperation, e.g., on climate protection). In this counterfactual case, group K always chooses I so that the sequential game is reduced to two stages.

If group K's coalition formation is prohibited so that the members of group K act independently, then country M's technology choices are as follows. When $a < a_1$, country M obtains utility u_M^{OI} when choosing the old technology O and obtains utility u_M^{NI} when choosing the new technology N. Then, we have

$$u_M^{OI} - u_M^{NI} = \frac{aw_K^2}{(1+a)(2+k)^2}\,[\underbrace{k^2 - (1+a)b^2}_{>0 \text{ from } a \le a_1}] > 0,$$

implying that country M chooses the old technology. When $a \geq a_1$, country M obtains utility u_M^{OI} when choosing the old technology O and obtains utility $u_M^{NI}|_{g_{Ki}=0}$ when choosing the new technology N. Then, we have

$$u_M^{OI} - u_M^{NI}|_{g_{Ki}=0} = w_K^2 \left[\left(\frac{b+k}{k+2} \right)^2 - \frac{(1+a)b^2}{4} \right] \gtreqless 0 \;\Leftrightarrow\; a \lesseqgtr a_4,$$

where

$$a_4 \equiv \frac{k(2-b)\,[4b + k(b+2)]}{b^2(k+2)^2}. \tag{5}$$

From (1), (3), and (5), we have $a_1 < a_4 < a_3$ because

$$a_3 - a_4 = \frac{4k^2(2b-1) + 2b(k^3 - 2b)}{(2+k)^2 b^2} > 0 \quad \text{and} \quad a_1 - a_4 = -\frac{2(2-b)(k-2b)}{(2+k)^2 b^2} < 0.$$

In sum, if group K's coalition is prohibited, country M chooses the old technology for $a \leq a_4$ and the new technology for $a > a_4$.

Now, we compare the total public good supply in the case of endogenous coalition formation with the case where coalition formation is prohibited. Proposition 1 shows that the total public good supply in the SPNE of endogenous coalition formation is $G^{OC}|_{g_M=0}$ as long as $a < a_3$. Thus, when $a \leq a_4$, we have

$$G^{OC}|_{g_M=0} - G^{OI} = \frac{w_K}{2(k+2)}(k^2 - 2b) > 0.$$

When $a > a_4$, we have

$$G^{OC}|_{g_M=0} - G^{NI}|_{g_{Ki}=0} = \frac{w_K}{2}\left[k - (1+a)b\right] \gtreqless 0 \;\Leftrightarrow\; a \lesseqgtr a_5,$$

where

$$a_5 \equiv \frac{k-b}{b}. \tag{6}$$

From (3), (5), and (6), we find that

$$a_5 - a_4 = \frac{b[k(k^2-4) - 4b] + 4k^2(b-1)}{(2+k)^2 b^2} > 0 \;\text{ and }\; a_3 - a_5 = \frac{k}{b} > 0,$$

showing that $a_4 < a_5 < a_3$ holds. The comparison of the total public good supply shows that when the technology parameter is large enough $a > a_5$, the total public good supply in the SPNE with endogenous coalition formation is smaller than that in the counterfactual situation where building a coalition is prohibited. Now, we have the following proposition.

Proposition 2. *(Coalition paradox on the total public good supply)*
If $a > a_5 = (k-b)/b$, then the possibility of forming a coalition between the countries in group K leads to a lower total provision of the public good.

The intuition behind this result is the following: When $a > a_4$, country M has an incentive to adopt the new technology if group K does not have an option to form a coalition; it does not, however, if group K has the option. Thus, when the technology parameter is large enough ($a > a_5$), the unfavorable effect on the total public good provision caused by M's decision not to adopt the superior new technology dominates the effect of cooperative coalition formation by group K.

As a further step, we compare the aggregate world welfare in two cases. Proposition 1 shows that the aggregate world welfare in the SPNE with endogenous coalition formation is $TU^{OC}|_{g_M=0}$ as long as $a < a_3$. When $a \leq a_4$, we have

$$TU^{OC}|_{g_M=0} - TU^{OI} = \frac{w_K^2}{4(k+2)^2}(k^2-2b)[k^2 + 2(1+k)b] > 0.$$

When $a > a_4$, we have

$$TU^{OC}|_{g_M=0} - TU^{NI}|_{g_{Ki}=0} = \frac{w_K^2}{4}\left[(1+a)b^2 + 2ab - k^2\right] \gtreqless 0 \quad\Leftrightarrow\quad a \lesseqgtr a_6,$$

where

$$a_6 \equiv \frac{k^2 - b^2}{2k + b} < a_3. \tag{7}$$

Proposition 3. *(Coalition paradox on world welfare)*
When $a > a_6 = (k^2 - b^2)/(2k + b)$, then the possibility of forming a coalition between the countries in group K leads to less aggregate world welfare.

Propositions 2 and 3 show that the possibility of coalition building by a group of countries may eliminate the incentive to develop and adopt a more productive contribution technology by another country, which, in the end, may lead to a lower public good supply and to less aggregate welfare.

In addition, from (6) and (7), we have

$$a_5 - a_6 = \frac{k(k - b)}{b(2k + b)} > 0,$$

which implies that the coalition paradox on world welfare occurs for a smaller threshold technology parameter than that on the total public good supply. Note that the critical threshold values of a_5 and a_6 for obtaining the results of the coalition paradox are not extraordinarily high. If, e.g., $w_M = 15$, $w_K = 10$, and $k = 5$, we have $a_5 = 2.33$ and $a_6 = 1.32$. Figure 3 illustrates the relationship between the critical threshold values of technology parameters, a_5 and a_6, and the number of countries in group K. In the figure, the area above the a_5 (a_6) line indicates the area in which the result of coalition paradox on the total public good supply (world welfare) occurs.

Note that in cases where k is smaller than 4 (i.e., $k = \{2, 3\}$), two coalition paradoxes may seem less likely, but in fact, this requires a more detailed analysis. This is because when k is small, group K may have no incentive to form a coalition, even if country M chooses the old technology. The details are presented in Appendix A1.

8 Concluding Remarks

Interstate cooperation and better technology are important factors in mitigating the underprovision of global public goods. This paper has suggested that future interstate (partial) cooperation would hinder the current adoption of better technology by a country outside the cooperating group, which may exacerbate the underprovision problem.

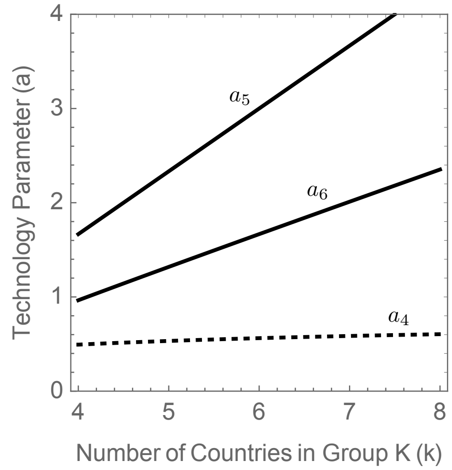

Figure 3: The critical threshold values for coalition paradoxes for $w_K = 10$ and $w_M = 15$

The results have an important policy implications for global climate policy. If a large country hesitates to develop and apply improved greenhouse gas abatement technologies and thus announces lower nationally determined contributions (NDCs) (or in the extreme case, even withdraws from the agreement entirely as the US had planned under Trump's presidency), this can be explained by strategic motives, i.e., as an attempt to motivate other countries to form a coalition of the willing, or a "climate club" in Nordhaus' terminology (Nordhaus 2015). Then, paradoxically, reducing the readiness of the other countries to cooperate can provide the large country with greater incentives to develop environmental technologies, which might – as has been shown in this paper – lead to a higher level of global climate protection and higher global welfare. Having such a strategy in mind casts at least some further doubts on the effectiveness of the bottom-up approach as intended by the Paris Agreement (see, e.g., Sandler 2017 or Dimitrov et al. 2019, for an assessment of the Paris Agreement).

Another practical application of our study relates to team production within a firm. If individuals in a team are evaluated or rewarded based on team performance, they tend to exert less effort on team projects (free-rider problem). Suppose there is one uncooperative member of a team who does not participate in the coalition where members agree to exert greater effort. Then, management or members in the coalition might consider replacing the uncooperative member with a new, more skilled person, but unless the new member join the coalition after the replacement has been made, the original coalition will be dissolved, resulting in lower team performance than before.

Our analysis can further be extended in several ways. One possible extension would be to endogenize not only the technology choices by a country outside a coalition but also those by countries inside the coalition. Depending on the types of coalition formation, the insider country may have no incentive to adopt better technologies, which may increase the country's burden within the coalition. This – if anticipated – may also hinder the formation of a coalition since, as indicated by Hoel (1991), Buchholz and Konrad (1994) and Beccherle and Tirole (2011), a country that unilaterally adopts better technology or some other pre-bargaining actions may harm its position in negotiations. Another possible extension would be to consider heterogeneous sensitivity to public goods among countries within the coalition. In that case, the country outside the coalition will decide whether to adopt a new technology, taking into account the extent to which the adoption will reduce the size of the coalition. These issues await future research.

Appendix

A1. The case of $k \in \{2, 3\}$

In this appendix, we consider the case where group K consists of fewer than four countries (i.e., the case of $k = 2$ or $k = 3$) and show how our results can be modified.

In the case of $k = 2, 3$, the derivation of the third-stage equilibrium for Cases OI and NI in Sections 3.1 and 3.2 remains the same as before. In Case OC, when $k < 2b$, there exists an equilibrium with interior solutions, meaning that country M, which does not adopt the new technology will become a positive contributor even if group K forms a coalition. Thus, for $k < 2b$, the interior-solution equilibrium is characterized by

$$g_{Ki}^{OC} = \frac{2k\,w_K - w_M}{3k}, \quad g_M^{OC} = \frac{2w_M - k\,w_K}{3}, \quad G^{OC} = \frac{k\,w_K + w_M}{3},$$
$$u_{Ki}^{OC} = \frac{1}{k}\left(\frac{k\,w_K + w_M}{3}\right)^2, \quad u_M^{OC} = \left(\frac{k\,w_K + w_M}{3}\right)^2, \quad TU^{OC} = k\,u_{Ki}^{OC} + u_M^{OC},$$

and for $k \geq 2b$, the equilibrium is the same as in the main body. Thus, the smaller k is, the less likely it will be that country M becomes a free rider.

In Case NC, the assumption on k affects only the threshold value a_2, below which country M

becomes a free rider. Thus, given the values of a and b, the smaller k is, the less likely it will be for country M to become a free rider.

Next, we consider coalition formation at the second stage. When $k \geq 2b$, the analysis is the same as in the case of $k \geq 4$ in the main body. When k is small such that $k < 2b$, comparing u_{Ki}^{OI} with u_{Ki}^{OC}, we have

$$u_{Ki}^{OI} - u_{Ki}^{OC} = \frac{(kw_K + w_M)^2}{(k+2)^2} - \frac{(kw_K + w_M)^2}{9k} > 0$$

for $k = \{2, 3\}$, which implies that group K will not form a coalition when country M does not adopt a new technology. Thus, Lemma 1 is modified as follows:

Lemma 3. *Consider the case of $k = \{2, 3\}$. If country M chooses the old technology at the first stage, then group K forms a coalition for $k \geq 2b$ and does not form a coalition for $k < 2b$ at the second stage.*

Now, we investigate group K's incentive to form a coalition when country M adopts a new technology. The difference with the main body is the relationship between the threshold values a_1 (above which each country Ki becomes a noncontributor in Case NI), a_2 (below which country M becomes a noncontributor in Case NC), and a_3 (above which group K becomes a noncontributor in Case NC): we have $a_2 < a_1 < a_3$ because

$$a_2 - a_1 = \frac{k-4}{2b} < 0 \quad \text{and} \quad a_3 - a_1 = \frac{2(k+1)}{b} > 0.$$

In addition, we have $a_2 \leq 0$ if $k \leq 2b$. Hence, we can distinguish four regions for the productivity parameter a:

(i) If $k > 2b$ (which excludes the case of $k = 2$), then $a_2 > 0$. When $0 \leq a < a_2$, we find, from (4) and $k = 3$, that

$$u_{Ki}^{NI} - u_{Ki}^{NC}|_{g_M=0} = \frac{w_K^2}{100}\left[4(1+a)^2b^2 + 24(1+a)b - 39\right] \lesseqgtr 0 \quad \Leftrightarrow \quad a \lesseqgtr a_7 \equiv \frac{5\sqrt{3}-6}{2b} - 1 < a_2,$$

which implies that, for $k = 3$, group K has an incentive to form a coalition only when $a < a_7$.

(ii) When $a_2 \leq a < a_1$, we have

$$u_{Ki}^{NI} - u_{Ki}^{NC} = \left(\frac{kw_K + (1+a)w_M}{k+2}\right)^2 - \left(\frac{kw_K + (1+a)w_M}{3k^2}\right)^2 > 0 \quad \text{for} \quad k = \{2, 3\},$$

which implies that group K does not form a coalition.

(iii) When $a_1 < a \leq a_3$, we have

$$u_{Ki}^{NI}|_{g_{Ki}=0} - u_{Ki}^{NC} = \frac{w_K^2}{18k}\Big[\underbrace{2(1+a)b-k}_{>0 \text{ from } a>a_1>a_2}\Big]\Big[\underbrace{2k-(1+a)b}_{\geq 0 \text{ from } a \leq a_3}\Big] \geq 0,$$

which implies that group K does not form a coalition.

(iv) When $a > a_3$, group K is indifferent between forming and not forming a coalition as in the main body.

Lemma 4. *Consider the case of $k = \{2, 3\}$. If country M chooses the new technology, then group K does not form a coalition, except for the case where $k \geq 2b$ and $a < a_7$.*

Now, we investigate country M's technology choice at stage 1. First, when $k < 2b$, country M expects that group K never has an incentive to form a coalition, which is exactly the same as in the situation where building a coalition is prohibited as presented in Section 6. Therefore, the country chooses the old technology for $a \leq a_4$ and the new technology for $a > a_4$.

Second, when $k \geq 2b$, group K forms a coalition if country M chooses old technology, but it does not do so if country M chooses new technology, except for $a < a_7$. Since

$$a_1 - a_7 = \frac{5(2-\sqrt{3})}{2b} > 0,$$

we can distinguish three regions for the productivity parameter a:

(a) When $a < a_7$, we have $u_M^{OC}|_{g_M=0} - u_M^{NC}|_{g_M=0} = 0$, implying that country M has no incentive to adopt new technology.

(b) When $a_7 \leq a < a_1$, we have

$$u_M^{OC}|_{g_M=0} - u_M^{NI} = \frac{w_K^2}{2(1+a)(k+2)^2}\Big\{\underbrace{(1+a)b[k^2(4+k)-2(1+a)b]-2k^2}_{>0 \text{ from } a<a_1}\Big\} > 0,$$

which implies that country M has no incentive to adopt new technology.

(c) When $a > a_1$, we have

$$u_M^{OC}|_{g_M=0} - u_M^{NI}|_{g_{Ki}=0} = \frac{w_K^2}{4}\left[2k - (1+a)b\right] \gtreqless 0 \quad \Leftrightarrow \quad a \lesseqgtr a_3.$$

Now, we have the following proposition on the SPNE for the case of $k = \{2, 3\}$.

Proposition 4. *Suppose $a < a_3$ and $k = \{2, 3\}$. In the subgame-perfect Nash equilibrium (SPNE) of the game, country M adopts a new technology only if $k < 2b$ and $a > a_4$ hold simultaneously. Otherwise, it never has an incentive to adopt a new technology.*

The intuition behind Proposition 4 is simple: if group K consists of a small number of countries and/or it has smaller incomes such that $k < 2b$, the group's incentives to form a coalition would shrink due to the greater negative reactions by the outsider country M. That, in turn, would incentivize country M to adopt the new technology without fear of disturbing the coalition of group K.

Since the equilibrium in the case of $k < 2b$ is the same as that in the case where building a coalition is prohibited, the two coalition paradoxes in the main body also hold for $k \geq 2b$, but do not hold for $k < 2b$.

A2. Quasi-linear utility case

Here we consider a case of quasi-linear utility,

$$u_j = c_j + 2\beta\sqrt{G},$$

which is often assumed in the literature. As is well known, in this utility formulation without income effects, even a small heterogeneity among countries leads to a corner-solution equilibrium, which makes our analysis simple. Moreover, there is no need for Assumptions 1 and 2 to obtain two coalition paradoxes.

The third-stage equilibrium of Case OI is as follows:

$$g_{Ki}^{OI} = g_M^{OI} = \frac{\beta^2}{k+1}, \quad G^{OI} = \beta^2, \quad u_{Ki}^{OI} = w_K + \frac{(2k+1)\beta^2}{k+1}, \quad u_M^{OI} = w_M + \frac{(2k+1)\beta^2}{k+1},$$

and $TU^{OI} = k\, u_K^{OI} + u_M^{OI}$. In this case, there are many Nash equilibria because all countries have symmetric production technology, but we focus on the symmetric equilibrium in which all countries are positive and equal contributors.

In Case NI, countries Ki are necessarily becoming free riders. The equilibrium consists of

$$g_K^{NI}|_{g_{Ki}=0} = 0, \quad g_M^{NI}|_{g_{Ki}=0} = (1+a)\beta^2, \quad G^{NI}|_{g_{Ki}=0} = (1+a)^2\beta^2,$$

$$u_K^{NI}|_{g_{Ki}=0} = w_K + 2(1+a)\beta^2, \quad u_M^{NI}|_{g_{Ki}=0} = w_M + (1+a)\beta^2,$$

and $TU^{NI}|_{g_{Ki}=0} = k\, u_K^{NI}|_{g_{Ki}=0} + u_M^{NI}|_{g_{Ki}=0}$.

In Case OC, country M becomes a free rider. Thus, the equilibrium is

$$g_K^{OC}|_{g_M=0} = \beta^2 k, \quad g_M^{OC}|_{g_M=0} = 0, \quad G^{OC}|_{g_M=0} = \beta^2 k^2,$$

$$u_K^{OC}|_{g_M=0} = w_K + \beta^2 k, \quad u_M^{OC}|_{g_M=0} = w_M + 2\beta^2 k,$$

and $TU^{OC}|_{g_M=0} = k\, u_K^{OC}|_{g_M=0} + u_M^{OC}|_{g_M=0}$.

Finally, in Case NC, the reaction functions of country Ki in a coalition and country M are as follows:

$$g_{Ki}(g_M) = \beta^2 k - \left(\frac{1+a}{k}\right) g_M \quad \text{and} \quad g_M(g_{Ki}) = \beta^2(1+a) - \left(\frac{k}{1+a}\right) g_{Ki},$$

which implies that country M becomes a free rider when $a < k-1$, whereas the countries in coalition K become free riders when $a > k-1$. When $a = k-1$, there are many Nash equilibria in the contribution stage (because the slopes and the intercepts of the reaction function for both country M and coalition K are the same). Therefore, we omit just the case of $a = k-1$ to avoid the problem of equilibrium selection. Figure 4 depicts the Nash equilibrium (NE) for $a < k-1$ (the left panel) and for $a > k-1$ (the right panel). When $a < k-1$, the equilibrium is the same as Case OC, whereas when $a > k-1$, the equilibrium is the same as Case NI.

Then, we derive the second-stage coalition formation choices of group K. If country M chooses the old technology, then group K always chooses to form a coalition because

$$u_K^{OI} - u_K^{OC}|_{g_M=0} = -\frac{k^2-k-1}{k+1}\beta^2 < 0.$$

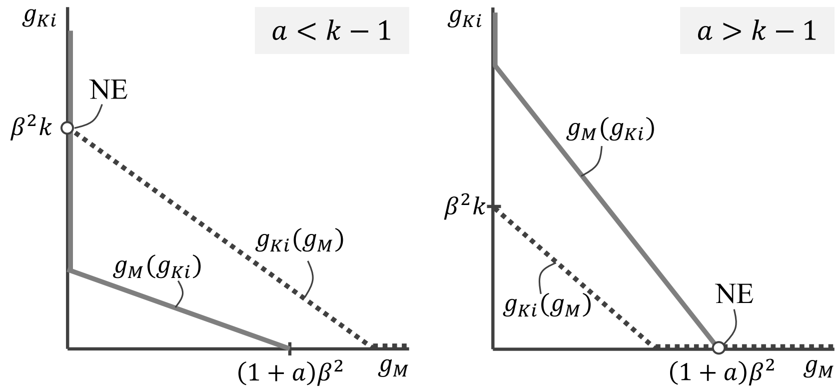

Figure 4: The third-stage Nash equilibrium in Case NC for $a < k - 1$ and $a > k - 1$

If country M chooses the new technology, we have

$$u_K^{NI}|_{g_{Ki}=0} - u_K^{NC}|_{g_M=0} = [2(1+a) - k]\beta^2 \begin{cases} < 0 & \text{for} \quad a < \frac{k-2}{2}, \\ \geq 0 & \text{for} \quad \frac{k-2}{2} \leq a < k-1, \end{cases}$$

$$u_K^{NI}|_{g_{Ki}=0} - u_K^{NC}|_{g_{Ki}=0} = 0 \qquad \text{for} \quad a \geq k - 1.$$

Therefore, group K forms a coalition if $a < (k-2)/2$, otherwise, it does not form a coalition.

Now, we derive the first-stage choice of country M. If country M chooses the old technology, then coalition K will be formed, and country M can free ride on it, which gives country M utility $u_M^{OC}|_{g_M=0}$. If country M chooses the new technology, group K forms a coalition for $a < (k-2)/2$, which gives country M utility $u_K^{NC}|_{g_M=0} = u_K^{OC}|_{g_M=0}$. Therefore, when $a < (k-2)/2$, country M has no incentive to adopt a new technology. When $a \geq (k-2)/2$, if country M adopts a new technology, then a coalition will not be formed. Then we have

$$u_K^{OC}|_{g_M=0} - u_M^{NI}|_{g_{Ki}=0} = [2k - (1+a)]\,\beta^2 \gtreqless 0 \quad \text{for} \quad a \lesseqgtr 2k - 1,$$

which implies that country M chooses the old technology when $a \leq 2k - 1$ and chooses new technology when $a > 2k - 1$.

Proposition 5. *Suppose that the utility function is given by the quasi-linear form $u_j = c_j + 2\beta\sqrt{G}$. In the SPNE of the game, country M does not have an incentive to adopt a new technology except for $a > 2k - 1$.*

We derive two results concerning the coalition paradox in the quasi-linear utility case. When forming a coalition is prohibited, country M gets u_M^{OI} by not adopting the new technology and gets $u_M^{NI}|_{g_{Ki}=0}$ by adopting the new technology. Then we have

$$u_M^{OI} - u_M^{NI}|_{g_{Ki}=0} = \frac{k - a(k+1)}{k+1}\beta^2 \gtreqless 0 \quad \text{for} \quad a \lesseqgtr \frac{k}{k+1}.$$

Thus, country M chooses the old (new) technology when $a \leq k/(k+1)$ ($a > k/(k+1)$) under the prohibition of group K's coalition formation.

Now, we show the result of the coalition paradox on the total public good supply. When $0 \leq a < k/(k+1)$, we have $G^{OC}|_{g_M=0} - G^{OI} = (k^2-1)\beta^2 > 0$, implying that the total public good supply in the SPNE of endogenous coalition formation is larger than that in the case where forming a coalition is prohibited. In contrast, when $k/(k+1) \leq a < 2k-1$, we have

$$G^{OC}|_{g_M=0} - G^{NI}|_{g_{Ki}=0} = \left[k^2 - (a+1)^2\right]\beta^2 \gtreqless 0 \quad \text{for} \quad a \lesseqgtr k-1.$$

Finally, when $a > 2k-1$, both regimes yield the same total public good supply, $G^{NI}|_{g_{Ki}=0}$. Thus, we have the following proposition:

Proposition 6. *(Coalition paradox on the total public good supply)*
Suppose that the utility function is given by the quasi-linear form. When $k-1 \leq a < 2k-1$, then the possibility of forming a coalition between group K leads to a lower total provision of public goods.

Now, we show the results of the coalition paradox on world welfare. When $0 \leq a < k/(k+1)$, we have $TU^{OC}|_{g_M=0} - TU^{OI} = (k^2-1)\beta^2 > 0$, implying that the total utility in the SPNE of endogenous coalition formation is larger than that in the case where forming a coalitions is prohibited. In contrast, when $k/(k+1) \leq a < 2k-1$, it holds that

$$TU^{OC}|_{g_M=0} - TU^{NI}|_{g_{Ki}=0} = [k^2 - 1 - a(2k+1)]\beta^2 \gtreqless 0 \quad \text{for} \quad a \lesseqgtr \frac{k^2-1}{2k+1}.$$

When $a > 2k-1$, both regimes yield the same level of world welfare. Thus, we have the following proposition:

Proposition 7. *(Coalition paradox on world welfare)*

Suppose that the utility function is given by the quasi-linear form. When $\frac{k^2-1}{2k+1} \leq a < 2k-1$*, then the possibility of forming a coalition between group* K *leads to a lower level of world welfare.*

As in the Cobb-Douglas utility case presented in the main text, we have

$$(k-1) - \left(\frac{k^2-1}{2k+1}\right) = \frac{k(k-1)}{2k+1} > 0,$$

which implies that the coalition paradox on world welfare occurs for a smaller threshold technology parameter than that on the total public good supply, implying that the former is more likely to occur than the latter. For example, if $k = 2$, then a coalition paradox on total public good supply occurs for $a \in [1, 3)$ and that on world welfare occurs for $a \in [0.6, 3)$.

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