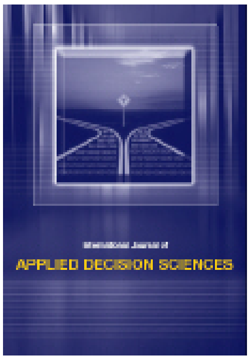

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# A signalling game for research fund allocation in Thailand

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**Abstract:** This study proposed a signalling game for a research grant allocation situation involving two players: a funding agency and a researcher whose type was kept secret from the funding agency, where the agency decided the grant amount to fund the researcher. The results showed that a pooling equilibrium existed when the difference between a large and small fund was sufficiently large, and the expected costs of failing the large-fund project for both types were small, whereas the expected costs of failing the small-fund project for both types were large. A case study was examined based on the research impact assessment of other studies. According to the results, we were still in a pooling equilibrium. However, if some model parameters changed (such as when the estimated cost of a penalty to a bad researcher was increased), a separating equilibrium began to show.

**Keywords:** game theory; signalling game; research funds allocation; decision analysis; Thailand.

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## 1 Introduction

Since 2020, Thailand's fund allocation structure has changed to be more centralised, with Thailand Science Research and Innovation (TSRI) serving as the primary responsible party. Nevertheless, funding decision approaches, such as peer-reviewed processes and committee group meetings, have remained unchanged. The seven program management units (PMUs) under TSRI are:

1. The National Research Council of Thailand (NRCT)
2. The National Innovation Agency (NIA)
3. The Agricultural Research Development Agency (ARDA)
4. The Health Systems Research Institute (HSRI)
5. The PMU Area-based (PMU A)
6. The PMU Brain-power and Manpower (PMU B)
7. The PMU Competitiveness (PMU C) (National Research Council of Thailand, 2016).

These PMUs are responsible for granting research funds to various research themes.

In 2020, TSRI allocated THB 12,554 million to all seven PMUs. Out of this amount, THB 8,383 million was allocated for flagship projects, with the remainder allocated for non-flagship projects. The NRCT managed the research funds for flagship projects and then distributed funds to subunit research agencies comprising governmental divisions and the private, higher education, and state enterprise sectors (National Research Council of Thailand, 2016). The largest expenditure for the NRCT was on the private sector (80%), followed by the higher education sector (14%). Out of this total amount to the NRCT, more than 50% of research projects were categorised as applied research

(National Research Council of Thailand, 2016). Thus, Thailand's research funding allocation is mainly a top-down system, in which the government allocates funds to major research funding management agencies, which then allocated funds to subunits and eventually to individual projects (Boonsaeng and Sobhon, 2007).

Typically, the research proposals submitted annually are peer-reviewed in a blind process. However, despite the peer-reviewing process, committees from each subunit's funding department have to meet and finalise the funding decision to fit within the limited budget. During the peer review or committee meeting processes, the grant amount for various proposals is determined on the basis of the probability of achieving the objective goals and an assessment of the potential research impact on the nation's development and knowledge foundation (Belcher et al., 2017). However, it is quite expensive to undertake a relatively complete and reliable assessment of the impact, which can be evaluated by several key economic indicators, such as the benefit-to-cost ratio (BCR) (Keisler, 2004). Thus, most decisions have been made primarily based on an individual's judgment and reviewers' opinions. Various aspects of bias in a resource allocation decision-making process have been investigated (Fujinaka and Sakai, 2009; Gamliel and Eyal, 2010; Shrivastava et al., 2017).

The scenario explored in this study was closely related to the contest theory in which players make a decision about the level of their efforts, aiming to win over the other opponents through many types of interactions, such as patent races, sports, military combat, and research allocations. This study examined the behaviour of a government funding agency and a researcher using the signalling game-theoretical model territory. We assumed that the funding agency was unaware of the identity of the researcher. Then, the equilibria of separating and pooling were investigated. This aspect was not addressed in other reported studies and is worth exploring since we assume that different researcher qualities (similar to the workforce market) exist in every nation.

## 2 Literature overview

The literature was reviewed to identify approaches to establishing a technique of allocating funds from the existing method to the method described in this study. Mutz et al. (2012) analysed the reliability of peers during a review process. Furthermore, several studies, particularly in the field of forestry, have focused on identifying factors that can impact the success of research funding. For example, Bartlett et al. (2017) identified important success factors affecting project outputs using a qualitative approach. The factors were classified into two stages: during the project design and the project implementation, from data collection of ten forestry projects funded by the Australian Center for International Agricultural Research implemented in Vietnam.

Few studies on projects prioritisation have been based on benefits, because the cost of assessing the impact of the proposed projects is relatively expensive in Thailand. For example, Keisler (2004) proposed using the BCR as a threshold for prioritising or selecting projects to fund. Bhattacharjya et al. (2013) extended the portfolio problem to include the scenario in which projects were dependent. Liesio (2014) proposed multi-objective portfolio decision analysis to optimally maximise portfolio values. Karaveg et al. (2014) proposed a technique to evaluate R&D commercialisation capability in another study that aimed to evaluate project capability. Jang (2019) proposed an approach for allocating the R&D funding of the Korean government's national R&D program based on economic profits. Hessami et al. (2020) proposed prioritising projects in a sustainability program at Texas A&M University based on the BCR. Frej et al. (2021) used a multi-attribute value function to assess each project benefit in order to prioritise 46 R&D projects of a big Brazilian electric energy company within the constraints of the available budget.

Heidenberger and Stummer (1999) reviewed several quantitative approaches to research funding allocation. The first approach discussed in the report was a quantitative evaluation of the research impact. Some studies applied either linear or nonlinear programming models to optimally solve project selection and resource allocation. Simulation and game-theoretical modelling were also discussed in that study. However, the game-theoretic modelling studies discussed in Heidenberger and Stummer (1999) only focused on strategic R&D expenditure when firms were competing for patents.

A considerable number of studies have used principal-agent modelling in the field of strategic research policy, with Guston (1996) being the first in the investigation of the policymaker's strategies for persuading scientists to conduct studies on the basis of public needs. In addition, Van der Meulen (1998) attempted to map the government's and scientists' objectives using a model that included rigorous analytical and empirical results, using case studies in the United Kingdom, Germany, and the Netherlands. Braun and Guston (2003) presented a comprehensive review of this subject. Gerchak and Schmid (2021) utilised principal-agent modelling to study how principals, who are solely impacted by their agents' best or lowest success, should establish their reward function. Matinheikki et al. (2022) investigated a division of agency concerns, comprising principal and agent features, to effectively operationalise agency expenditures.

Bias in various aspects of a resource allocation decision-making process has been investigated. Gamliel and Eyal (2010) investigated how negative and positive framing effects influenced the perceived fairness of healthcare resource allocation in a healthcare setting. Shrivastava et al. (2017) used the dictator game (List, 2007) to investigate a biased perception from numerosity and allocation behaviour. In particular, experiments were conducted to observe the decision maker's perception of whether the amount to allocate was perceived as too large or too small. They discovered that presenting the decision-maker with a significant numerical value tended to cause the decision-maker to allocate resources insufficiently. Furthermore, Fujinaka and Sakai (2009) investigated allocation efficiency using an ε-Nash equilibrium for any sufficiently small ε. In research funding allocation, bias was a critical issue (Mom and van den Besselaar, 2021). Bendiscioli (2019) and Sato et al. (2020) investigated the problem of expert funding decisions in research funding allocation, whereas Guthrie et al. (2019) clearly studied such concerns through rapid evidence evaluation and interviews with research funding agencies. Vinkenburg et al. (2022) contributed process optimisation in assessments and decisions for reducing bias in the allocation of research funding. Banal-Estañol et al. (2019) studied whether funding agencies were biased against diverse teams, which has been related to the production of transformational research. Philipps (2022) investigated scientists' perspectives on current funding conditions and the idea of random allocation for unbiased funding.

The scenario explored in this study is closely related to the contest theory in which players make a decision about the level of their efforts, aiming to win over the other opponents in many types of interactions such as patent races, sports, military combat, and research allocations (Ho et al., 2022; Konrad, 2007; Moyal and Ritov, 2020). Another related model is the Tullock contests (Tullock, 1980) which have been widely used to explore cases in which there is a set of fixed prices that would need to be mapped with a set of players. More recently, the Tullock contest model has been greatly extended by many researchers (for example, Chowdhury and Sheremeta, 2011; Dickson et al., 2022; Gamber et al., 2021; Lu et al., 2022; Munger, 2019). One example of Tullock model extension was reported in Ryvkin (2007) who explored the case when player heterogeneity was weak. Another example in Einy et al. (2017) allowed the cost of a players' efforts to be random, with the main objective being to explore the value of public information. Group contests have also been investigated, similar to those in Chowdhury et al. (2013) and Lim et al. (2014). The model has been adopted even more recently by Sela (2020) who extended it to consider both prizes and punishments in the case of multiple players and multiple states.

Extending the Tullock contest model, the current study evaluated the signalling game-theoretic model territory to examine the behaviour of a government funding agency and a researcher. We assumed that the information about the researcher's type was unknown to the funding agency. Then, separating and pooling equilibria were examined. This aspect had not been addressed in previous studies and is worth investigating because we believe in various researcher qualities (similar to the workforce market) that are present in every country.

## 3 Research methodology

There are two subsections under research methodology:

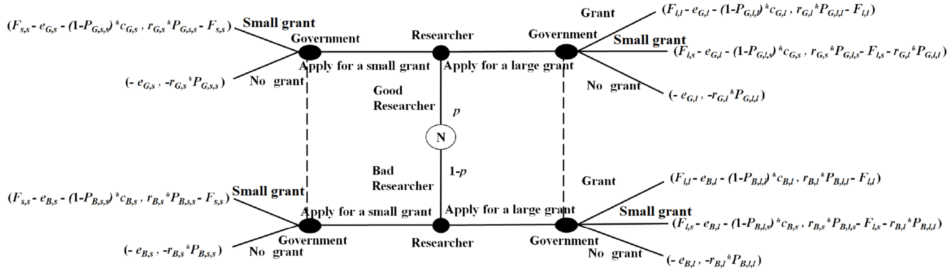
1 notation, model formulation, and assumptions

2 pooling and separating equilibria.

### 3.1 Notation, model formulation, and assumptions

As shown in Figure 1, we modelled the interaction between a national funding agency and a researcher in an extensive-form game. The funding agency had no means of knowing the type of researcher, which could be categorised as "good" or "bad." The terms "good" and "bad" were from a typical signalling game and were applied to easily refer to the type and did not imply that the researcher was good or bad. A good researcher could be assumed to be experienced and fully dedicated, whereas a bad researcher was inexperienced or not fully engaged in conducting the proposed study, resulting in a lower probability of success.

**Figure 1** Signalling game involving the government and a researcher



Both types of researchers were allowed to send a signal to the funding agency. The signal can be considered as the effort each type put into writing their proposal. Then, the governmental funding agency would consider the signal and decide on the amount of funding to grant to the researcher. In this model, the researcher was assumed to accept any amount provided by the government. Table 1 lists the notations of model parameters.

Figure 1 shows that payoffs to the government were calculated using the expected revenue minus the cost of conducting the study paid to the researcher and less the opportunity loss when the fund granted was less than the amount asked by the researcher. Since the probability ($p$), $0 \leq p \leq 1$ was assumed to be the government's belief in the percentage that the researcher was a good researcher, the expected payoff to the government, $E(UG_{s,k})$ and $E(UG_{l,k})$ was calculated by weighting this probability when the researcher requested a small fund (left side in Figure 1) and a large fund (right side in Figure 1). In equations (1) and (2) below, we also introduced a variable $x$, where $x$ equals 1 if $j > k$ equals 0 otherwise (that is the government was facing an opportunity loss when the size of the granted fund was less than what was requested by the researcher).

$$\begin{aligned} E(UG_{s,k}) = {} & p(r_{G,k}P_{G,s,k} - F_{s,k} - r_{G,s}P_{G,s,s}x) \\ & +(1-p)(r_{B,k}P_{B,s,k} - F_{s,k} - r_{B,k}P_{B,s,s}x), \quad \forall k \end{aligned} \tag{1}$$

$$\begin{aligned} E(UG_{l,k}) = {} & p(r_{G,k}P_{G,l,k} - F_{l,k} - r_{G,l}P_{G,l,l}x) \\ & +(1-p)(r_{B,k}P_{B,l,k} - F_{l,k} - r_{B,l}P_{B,l,l}x), \quad \forall k \end{aligned} \tag{2}$$

The expected impact or benefits from a research project were calculated by multiplying the value of the evaluated potential impact ($r_{i,k}$) by the success probability of achieving the evaluated impact ($P_{i,i,k}$). The government opportunity loss occurred when the funding agency offered a smaller fund than what the researcher had requested. The opportunity loss was assumed to be the expected reward that the government would have gained if the large fund had been granted. For example, when the researcher decided to request a large fund, the maximum expected reward to the government was fixed at $r_{i,k}P_{i,l,l}$, $\forall i$. Thus, regardless of whether the government decided to grant a small fund or no fund, the opportunity loss was the same for each type. Similarly, when the researcher decided to request a small fund, the opportunity loss to the government was maximum at $r_{i,s}P_{i,s,s}$, $\forall i$ since this was the maximum that the government would get after the researcher had decided to request the small fund. Some terms in equations (1) and (2) are 0. For example, when the government decided to decline the proposal, the reward, $r_{i,0}$, and the amount funded, $F_{j,0}$, are 0.

However, the expected utility to the researcher $E(UG_{i,j,k})$ was calculated using equation (3):

$$E(UR_{i,j,k}) = F_{j,k} - e_{i,j} - (1 - P_{i,j,k})c_{i,k}, \forall i, j, k. \tag{3}$$

According to equation (3), the researcher would receive a positive amount of funding from the government, less the cost of the effort spent on proposal writing, proposal defense, or project preliminary study, and finally less the penalty cost of a bad reputation when the project was not successfully carried on multiplied by the probability of failure. Similar to the governments expected utility, when the project was declined, $F_{j,0}$ and $c_{i,0}$ were 0.

**Table 1** Notation for model parameters

| *Parameter* | *Explanation* |
|---|---|
| $G$ | Good researcher |
| $B$ | Bad researcher |
| $s$ | Small grant |
| $l$ | Large grant |
| $i$ | Researcher type $i$, $i \in I = \{G, B\}$ |
| $j$ | Grant amount $j$ proposed by the researcher $j$, $j \in J = \{s, l\}$ |
| $k$ | Grant amount k decided by the governmental funding agency, $k \in K = \{0, s, l\}$ (0 means the proposal was rejected) |
| $a_i$ | The action of a researcher type $i$, $i \in I$ |
| $g(a_i = j)$ | The government funding agency action as a function of researcher type $i$, $i \in I$ asking for the fund size $j$, $j \in J$ |
| $F_{j,k}$ | Amount of research fund size $k$ that the governmental agency granted to a proposal asking for a fund of size $j(j \in J$ and $k \in K)$ |
| $P_{i,j,k}$ | The probability of successfully achieving the project goal when granted a fund of size $k$, $k \in K - \{0\}$, by a researcher of type $i$, $i \in I$ asking for the fund size $j$, $j \in J$ |
| $p$ | The probability believed by the governmental funding agency that the researcher is of a good type |
| $c_{i,k}$ | Penalty cost of having a bad reputation for the researcher type $i$ who received the fund size $k$ whose study was unsuccessful ($i \in J$ and $k \in K - \{0\}$) |
| $r_{i,k}$ | The impact (benefit) of the study from a researcher of type $i$ who obtained a grant size $k$, ($i \in I$ and $k \in K - \{0\}$) |
| $e_{i,j}$ | Cost/effort that a researcher of type $i$ exerted to write and present a proposal asking for a grant of size $j$, ($i \in I$ and $j \in J$) |

Before we solved for the equilibrium of the model, the following conditions were strictly assumed:

$$F_{*,l} \geq F_{*,s} \tag{4}$$

$$P_{G,*,k} \geq P_{B,*,k}, \ \forall k \tag{5}$$

$$P_{i,*,s} \geq P_{i,*,l}, \ \forall i \tag{6}$$

$$r_{G,k} \geq r_{B,k}, \ \forall k \tag{7}$$

$$r_{i,l} \geq r_{i,s} \ \forall i \tag{8}$$

$$c_{G,k} \geq c_{B,k} \ \forall k \tag{9}$$

$$c_{i,l} \geq c_{i,s}, \ \forall i \tag{10}$$

$$c_{i,l} \geq c_{i,s}, \ \forall i \tag{11}$$

$$e_{i,l} \geq e_{i,s}, \ \forall i \tag{12}$$

$$r_{i,l} P_{i,l,l} \geq r_{i,s} P_{i,*,s}, \ \forall i \tag{13}$$

$$r_{B,s}P_{B,*,k} \geq F_{*,k}, \ \forall k \tag{14}$$

As shown in equation (4), it was certain that the amount of the large fund was larger than that of the small fund. The fund amount only depended on the index $k$ (indicating the grant amount provided by the government) and not on the amount requested by the researcher. For equations (5) and (6), we assumed that the probability of a good researcher successfully conducting a study was no less than that of a bad researcher. Furthermore, the probability of successfully conducting a study when the amount of funding was small, was assumed to be no less than when the amount of funding was large, since smaller projects were assumed to be relatively easier to conduct. Additionally, the success probability did not depend on how much the researcher requested but on how much funding the researcher received. In terms of research impact, if the project was successful, a good researcher should yield a reward no less than that of a bad researcher, as shown in equation (7), and a large project should yield a reward no less than a small project, as shown in equation (8). As shown in equation (9), the penalty cost when the project was unsuccessful for a good researcher was assumed to be no less than that for a bad researcher, and as shown in equation (10), the penalty cost for a large unsuccessful project was assumed to be no less than that from a small unsuccessful project. Finally, we assumed that the effort to propose a project was not dependent on researcher type, as shown in equation (11), but rather on the project's size, as shown in equation (12).

Equations (13)–(14) were assumed to further verify the propositions. As shown in equation (13), we assumed that the expected reward when a researcher received a large fund was no less than that when the researcher received a small fund for all types of researchers. Furthermore, in equation (14), we assumed that the expected reward from a bad researcher was still no less than the amount of the fund for all fund sizes. These two assumptions cannot be true in all cases; however, it was still reasonable to assume such relationships, since they occur in several funding allocation scenarios.

## 3.2 Pooling and separating equilibria

On the basis of the model formulation, the Perfect Bayesian Equilibrium was used to identify both pooling and separating equilibrium. The resulting propositions were obtained as follows:

*Proposition 1:* There exists a pooling equilibrium: $a_i^* = l, \forall i, g^*(a_i^* = l) = l, \forall i$ and $a_i^* = s, \forall i, g^*\left(a_i^* = s\right) = s, \forall i,$ if and only if

$$F_{l,*} - F_{*,s} \geq \left(1 - P_{i,l,l}\right)c_{i,l} - \left(1 - P_{i,*,s}\right)c_{i,s} + \left(e_{i,l} - e_{i,s}\right), \forall i \tag{15}$$

Furthermore, if both types of researcher request a small fund, the government is always better off granting a small fund.

*Proof:* When both types of researcher request a large fund, the government prefers a large fund over a small fund when:

$$\begin{aligned} & p\left(r_{G,l}P_{G,l,l}-F_{l,l}\right)+(1-p)\left(r_{B,l}P_{B,l,l}-F_{l,l}\right)\geq p\left(r_{G,s}P_{G,l,s}-F_{l,s}-r_{G,l}P_{G,l,l}\right) \\ & \quad +(1-p)\left(r_{B,s}P_{B,l,s}-F_{l,s}-r_{B,l}P_{B,l,l}\right) \\ & p^{*}\geq\frac{r_{B,s}P_{B,l,s}-2r_{B,l}P_{B,l,l}+F_{l,l}-F_{l,s}}{2\left(r_{G,l}P_{G,l,l}-r_{B,l}P_{B,l,l}\right)-\left(r_{G,s}P_{G,l,s}-r_{B,s}P_{B,l,s}\right)}. \end{aligned} \tag{16}$$

When both types of researcher request a large fund, the government prefers a large fund over no funding when:

$$\begin{aligned} & p\left(r_{G,l}P_{G,l,l}-F_{l,l}\right)+(1-p)\left(r_{B,l}P_{B,l,l}-F_{l,l}\right)\geq p\left(-r_{G,l}P_{G,l,l}\right)+(1-p)\left(-r_{B,l}P_{B,l,l}\right) \\ & p^{*}\geq\frac{F_{l,l}-2r_{B,l}P_{B,l,l}}{2\left(r_{G,l}P_{G,l,l}-r_{B,l}P_{B,l,l}\right)} \end{aligned} \tag{17}$$

When both types of researcher request a small fund, the government prefers a small fund over no funding when:

$$\begin{aligned} & p\left(r_{G,s}P_{G,s,s}-F_{s,s}\right)+(1-p)\left(r_{B,s}P_{B,s,s}-F_{s,s}\right) \\ & \geq p\left(-r_{G,s}P_{G,s,s}\right)+(1-p)\left(-r_{B,s}P_{B,s,s}\right) \\ & p^{*}\geq\frac{F_{s,s}-2r_{B,s}P_{B,s,s}}{2\left(r_{G,s}P_{G,s,s}-r_{B,s}P_{B,s,s}\right)} \end{aligned} \tag{18}$$

To prove that there exists $p^{*}\in[0,1]$ that satisfies the above conditions: in equations (16)–(18), the right-hand sides (RHS) in these inequalities must be less than or equal to 1.

Since equations (5) and (7) guarantee that the denominator of equation (16) is greater than 0, the RHS of equation (16) is less than or equal to 1 when:

$$2\left(r_{G,l}P_{G,l,l}-r_{B,l}P_{B,l,l}\right)-\left(r_{G,s}P_{G,l,s}-r_{B,s}P_{B,l,s}\right)\geq r_{B,s}P_{B,l,s}-2r_{B,l}P_{B,l,l}+F_{l,l}-F_{l,s}$$

$$2r_{G,l}P_{G,l,l}-F_{l,l}\geq r_{G,s}P_{G,l,s}-F_{l,s}\geq r_{G,s}P_{G,l,s}-F_{l,l}$$

$$2r_{G,l}P_{G,l,l}\geq r_{G,l}P_{G,l,l}-F_{l,s}\geq r_{G,s}P_{G,l,s}$$

which satisfies equation (13).

The RHS of equation (18) is always less than or equal to 0. From the above, the denominator is always greater than 0. Thus, the numerator can be expanded as:

$$\left(r_{B,s}P_{B,l,s}-r_{B,l}P_{B,l,l}\right)-r_{B,l}P_{B,l,l}+\left(F_{l,l}-F_{l,s}\right). \tag{19}$$

Since the two terms in parentheses in equation (19) are less than or equal to 0 from equations (13) and (14), equation (18) is guaranteed to be less than or equal to 0. Hence, $p^{*}$ always exists.

Furthermore, since the denominator of equation (17) is always positive (as previously discussed) and since the numerator is always negative from equation (14) in the assumption, equation (17) is always true. Similarly, equation (18) is always true by following the proof for equation (17).

Finally, by checking that both types have no incentive to deviate, we need to check if:

$$F_{l,l}-e_{i,l}-\left(1-P_{i,l,l}\right)c_{i,l}\geq F_{s,s}-e_{i,s}-\left(1-P_{i,s,s}\right)c_{i,s},\ \forall i$$

$$F_{l,l} - F_{s,s} \geq \left(1-P_{i,l,l}\right)c_{i,l} - \left(1-P_{i,s,s}\right)c_{i,s} + \left(e_{i,l} - e_{i,s}\right),\ \forall i$$

satisfies equation (15) in the proposition.

*Lemma:* The pooling equilibrium $a_i^* = l, \forall i, g^*(a_i^* = l) = s, \forall i$ and $a_i^* = s, \forall i, g^*(a_i^* = s) = s,\ \forall i$ does not exist.

*Proof:* Following the above prove in equation (16), when both types of researchers request a large fund, the government prefers a small fund over a large fund when:

$$p^* \leq \frac{r_{B,s}P_{B,l,s} - 2r_{B,l}P_{B,l,l} + F_{l,l} - F_{l,s}}{2\left(r_{G,l}P_{G,l,l} - r_{B,l}P_{B,l,l}\right) - \left(r_{G,s}P_{G,l,s} - r_{B,s}P_{B,l,s}\right)}. \tag{20}$$

If $p^* \in [0, 1]$ exists, the RHS of equation (20) must be greater than 0. Unfortunately, the RHS of equation (20) is less than or equal to 0 as shown in the proof of the above proposition. Therefore, there is no such $p^* \in [0, 1]$ that satisfies the equation above.

*Lemma:* The pooling equilibrium of $a_i^* = l, \forall i, g^*(a_i^* = l) = 0,\ \forall i$ and $a_i^* = s,\ \forall i,$ $g^*(a_i^* = s)$ does not exist.

*Proof:* Since one of the required conditions for this pooling equilibrium is:

$$p^* \leq \frac{F_{l,l} - 2r_{B,l}P_{B,l,l}}{2\left(r_{G,l}P_{G,l,l} - r_{B,l}P_{B,l,l}\right)}. \tag{21}$$

The RHS of the above inequality must be greater than or equal to 0. However, from equation (14) in the assumption, this term is negative. Furthermore, from above, we have already proved that the denominator is positive. Equation (21) is always false.

*Proposition 2:* There exists a separating equilibrium: $a_G^* = l,\ a_B^* = s,\ g^*(a_G^* = l) = l,$ $g^*(a_B^* = s) = s,$ if and only if:

$$F_{l,l} - F_{*,s} \geq \left(1-P_{G,l,l}\right)c_{G,l} - \left(1-P_{G,*,s}\right)c_{G,s} + \left(e_{G,l} - e_{G,s}\right)$$

$$F_{l,l} - F_{*,s} \leq \left(1-P_{B,*,l}\right)c_{B,l} - \left(1-P_{B,*,s}\right)c_{B,s} + \left(e_{B,l} - e_{B,s}\right)$$

$$P_{G,*,l}c_{G,l} - P_{B,*,l}c_{B,l} \geq P_{G,*,s}c_{G,s} - P_{B,*,s}c_{B,s}$$

*Proof:* To begin, first, consider equation (22). To avoid contradiction, the RHS of equation (22) must be larger than that of equation (22).

$$\begin{aligned}&\left(1-P_{B,l,l}\right)c_{B,l} - \left(1-P_{B,*,s}\right)c_{B,s} + \left(e_{B,l} - e_{B,s}\right)\\&\quad \geq \left(1-P_{G,l,l}\right)c_{G,l} - \left(1-P_{G,*,s}\right)c_{G,s} + \left(e_{G,l} - e_{G,s}\right)\end{aligned}$$

$$\left(1-P_{B,l,l}\right)c_{B,l} - \left(1-P_{B,*,s}\right)c_{B,s} \geq \left(1-P_{G,l,l}\right)c_{G,l} - \left(1-P_{G,*,s}\right)c_{G,s}$$

$$P_{G,l,l}c_{G,l} - P_{B,l,l}c_{B,l} \geq P_{G,*,s}c_{G,s} - P_{B,*,s}c_{B,s} \tag{22}$$

If equation (22) were assumed, the above equation would be true.

*Lemma:* There exists a second separating equilibrium: $a_G^* = s$, $a_B^* = l$, $g^*(a_G^* = s) = s$, $g^*(a_B^* = l) = l$, if and only if:

$$F_{l,l} - F_{*,s} \le \left(1 - P_{G,l,l}\right) c_{G,l} - \left(1 - P_{G,*,s}\right) c_{G,s} + \left(e_{G,l} - e_{G,s}\right)$$

$$F_{l,l} - F_{*,s} \ge \left(1 - P_{B,l,l}\right) c_{B,l} - \left(1 - P_{B,*,s}\right) c_{B,s} + \left(e_{B,l} - e_{B,s}\right)$$

$$P_{G,*,l} c_{G,l} - P_{B,*,l} c_{B,l} \le P_{G,*,s} c_{G,s} - P_{B,*,s} c_{B,s}$$

*Proof:* This is immediate.

**Figure 2** Pooling and separating equilibria (case 1) (see online version for colours)

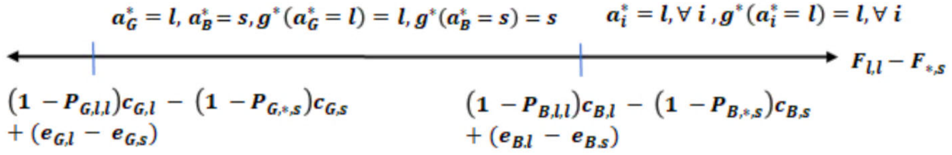
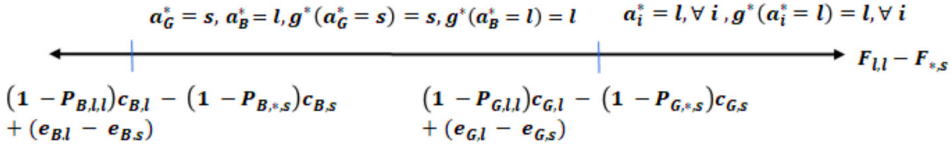


**Figure 3** Pooling and separating equilibria (case 2) (see online version for colours)



## 4 Case study

This section describes a case study of a typical research funding scenario in Thailand. We used the case study of rice studies in Thailand as explained in Jaijit et al. (2017, 2019). Jaijit et al. (2017) attempted to evaluate the research impact of three selected rice studies in the areas of breeding, production, and processing, respectively, whereas Jaijit et al. (2019) investigated the relationships between research funding and research outcomes (such as crop productivity, farmers' income, and plantation cost). These three projects received funding of THB 38 million, THB 36 million, and THB 25, respectively. Thus, in our context, we assumed that a large-fund project cost approximately THB 30 million. For a small-fund project, we assumed that the upper bound was approximately THB 5 million. Typically, several funding sources have funded small basic studies in the range of THB 0.2–0.5 million. However, in our context, a small fund should also yield a tangible impact, which would require a slightly larger fund than was typical in the small basic studies.

According to Jaijit et al. (2017), the ex-ante impact assessment for the three areas of rice studies yielded net present values of THB 1,251 million, THB 289 million, and THB 1,356 million, respectively. These assessments can be used as the impact from a good researcher obtaining a large fund in the study, $r_{G,l}$. If $r_{G,s}$ was assumed to have an upper bound of THB 100 million, to guarantee that equation (13) still held, $r_{G,l}P_{G,l,\,l}$ must be no less than 100. When $r_{G,l}$ was at a lower bound (assessed to be THB 289 million), the probability $P_{G,l,l}$ must be greater than 0.346 for all propositions above to be true. However, when $r_{G,j}$ = THB 1,356 million (at the upper bound), $P_{G,l,l}$ was only needed to be greater than 0.074 for the propositions to be true. Furthermore, if we assumed that the other parameters followed equations (4) to (14); thus, propositions 1 and 2 and the additional lemmas can be applied.

Since the differences between the effort of composing a project proposal for a large-fund project and a small-fund project for all types of researchers were negligibly small, we could omit these differences from the calculation. In addition, if the probability of successfully achieving the project goals for small-fund projects for both types is assumed to be 1, this term can also be omitted from the calculation.

What remained to consider was the difference between the large and small funds (which was THB 25 million) and the assessment of the penalty costs of failing the project. A good researcher was assumed to earn THB 5 million annually. If for some reason, the current large-fund project failed, the good researcher's future proposals were assumed to be rejected for approximately five years, then $c_{G,l}$ = THB 25 million. Similarly, a bad researcher was assumed to earn THB 1 million annually, with the same penalty duration, $c_{B,l}$ = THB 5 million. From Figures 2 and 3, we concluded that with the assessment in this case study, both types of researchers preferred to request large funds and the government would also grant a large fund. However, if the estimated cost of the penalty to the bad researcher was increased such that $(1 - P_{B,l,l})c_{B,l}$ was larger than THB 25 million, a separating equilibrium emerged, in which a good researcher requested a large fund and a bad researcher requested a small fund. Similarly, decreasing the difference between the large and small funds resulted in a reasonable separating equilibrium.

## 5 Discussion

The previous section showed that only one pooling equilibrium existed, in which both types of researchers requested a large fund existed. This was due to the assumption that the expected benefit from a study for a large fund was large for both types of researchers. Another assumption that the expected benefit from a study was greater than the funding cost was also needed to guarantee a unique pooling equilibrium.

The criteria that we used to separate a pooling equilibrium from a separating equilibrium in this current study was the difference between the large fund and the small fund. As shown in Figures 2–3, the equilibria were considered in two cases. In these figures, case 1 occurs when:

$$\begin{aligned}&\left(1-P_{B,l,l}\right)c_{B,l}-\left(1-P_{B,*,s}\right)c_{B,s}+\left(e_{B,l}-e_{B,s}\right)\\&\quad\geq\left(1-P_{G,l,l}\right)c_{G,l}-\left(1-P_{G,*,s}\right)c_{G,s}+\left(e_{G,l}-e_{G,s}\right)\end{aligned}$$

whereas case 2 is the reverse relationship.

Thus, a pooling equilibrium existed when the difference between the large and small funds was sufficiently large. Furthermore, pooling equilibrium occurred when the expected costs of failing the large-fund project for both types were small, whereas the expected costs of failing the small-fund project for both types were large. Pooling equilibrium also occurred when the difference between the effort of producing a project proposal for a large-fund project and a small-fund project was relatively small. The expected cost of failing the large-fund project was sufficiently large for the bad researcher, while if the expected cost of failing the large-fund project for the good researcher was sufficiently small, a reasonable separating equilibrium occurred (the good researcher requested a large fund and the bad researcher requested a small fund). For a small-fund project, the relationship was reversed. Furthermore, the difference in the cost of composing a proposal between a large fund project and a small fund project should be small for a good researcher and large for a bad researcher. The separating equilibrium when a good researcher requested a small fund project and a bad researcher requested a large fund project required the opposite relationships to what was explained.

## 6 Conclusions

This study developed a signalling game for a research funding allocation scenario in which the funding agency had no information about the re-searcher type. From the literature review, no attempt has yet been made to investigate strategic funding amount decisions by considering each re-searcher's characteristics (represented as type in this current study).

The results in the case study implied that research funding allocation was at a pooling equilibrium in Thailand, in which both types of researchers request large funds. This result was not unexpected, considering that the gap between a large and a small fund can be substantial. Furthermore, the expected penalty cost of failing a large-fund project for any type of researcher must be sufficiently high, whereas the expected penalty cost of failing a small-fund project should be relatively small.

The Thai government can carry out better research-funding allocation by adopting the results from our study. To achieve a higher percentage of good type researchers, the government should impose a relatively large penalty for failing a large-fund project that can deter a bad type from submitting a proposal for this large fund. A penalty example can be introduced, such as applying a blacklist across many funding agencies. For a bad type, such as researchers who may not yet have sufficient experience, the government should offer substantial, attractive small grants but should apply short-term performance evaluation for another small-grant extension. Penalties for small-grants should not be too costly to deter newly graduated researchers or any other researchers who may not yet have research-fund management experience.

However, it remains challenging to evaluate all model parameters. Nevertheless, to make a better decision, basic assessments should be used, such as the ex-ante technique for assessing the impact of a study. Assumptions about the researcher type can be inferred by a government funding agency, generally on the basis of the past study performance, researcher age, or interests. Haruechaiyasak et al. (2009) and Sense (2012) proposed approaches for building researcher networks that could be integrated into this study to assess the success probability on the basis of the researcher network. Haruechaiyasak et al. (2009) investigated research networks from a bibliographical dataset of Thai researchers.

The study could be a steppingstone to model strategic research funding allocation and model assumptions could be further relaxed to capture additional realistic applicable cases. Since researchers continuously request research funding over many years, a repeated game could be used to capture the effect of failure percentage on achieving the project goals. However, a repeated game can capture the effect on the researcher when the project is completed successfully. The bias that may arise during the decision-making process for research funding allocation should also be investigated further.

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